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Battle River Soil Reconstruction Project Five Year Summary

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RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

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To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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BATTLE RIVER SOIL
RECONSTRUCTION PROJECT
FIVE YEAR SUMMARY

by

L.A. Leskiw

CAN-AG ENTERPRISES LTD.

Prepared for

The Plains Coal Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
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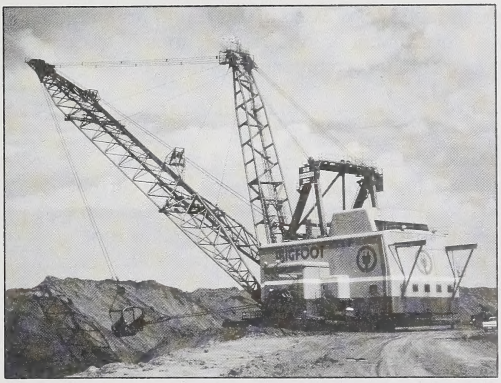

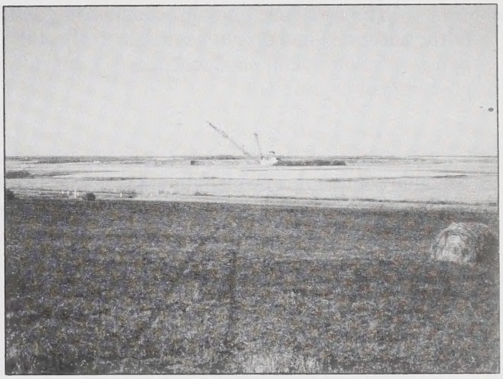

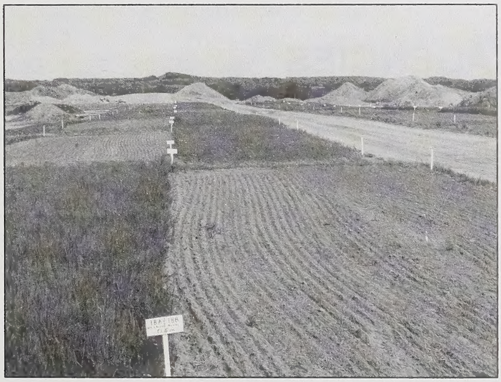

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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

The techniques used to construct the plots for this study have resulted in soil properties (notably compaction) which do not necessarily reflect the properties in land reclaimed using current operational methods. Therefore, the crop yields reported for the plots may be lower than what can be expected in the larger reclaimed fields. This is particularly true for the cereals, whose shallow root systems are much more dependent on the chemical and physical characteristics of surface soil. Cereal crops are being grown in operationally reclaimed fields in the Battle River region.

CO-FUNDING AGENCIES

RRTAC would like to thank Alberta Power Limited, Luscar Ltd., and Manalta Coal Ltd. for funding the initial construction activities, and for their continued participation with the management of the project with TransAlta Utilities Corporation and the Plains Coal Reclamation Research Program.

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1. Olson Brothers - Conducted the crop maintenance aspects of the study.
2. Double D Drilling - Provided a rig and operators to assist with soil sampling.
3. Norwest Labs - Conducted the laboratory analysis.
4. Dr. D. Chanasyk, University of Alberta, reviewed and discussed project work and reports.

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EXECUTIVE SUMMARY

The Battle River Soil Reconstruction Project (BRSRP) five-year report describes the project history and then presents for each of the four experiments, the results, interpretations and limitations of the research. Key findings arising from each experiment are highlighted next, focussing on crop yields, soil salinity, soil moisture, bulk density and root distribution.

BACKGROUND

At the time the project was being designed, some of the key questions to be answered included:

1. what is the minimum thickness of subsoil to be replaced over sodic mine spoil?
2. will salt move upward from the spoil and how serious is this potential problem?
3. what will cereal and forage yields be on reclaimed lands?
4. how effective are gypsum and ash as surface or subsurface amendments? and,
5. what are the topographic effects in this environment?

Literature data concerning crop responses, subsoil thickness, salt movement and moisture movement generally match results obtained in this study. Some very important findings of the BRSRP experiments that, in retrospect, had not received enough attention initially include: subsoil compaction, soil structure, density, porosity, and moisture availability. How can materials be handled to improve the physical properties of reclaimed lands? How will this affect soil chemical properties and soil development? The need for research on this subject has now been recognized and deserves more attention.

AGRONOMIC ACTIVITIES

Soil and crop management practices used on the plots were those conventionally used by farmers in the area, except for the use of small implements (40 HP, 3-point hitch tractor). A cultivator was used for seed-bed preparation and fall cultivation. Cereals were seeded with a press drill. Fertilizer was broadcast each spring on forage and cereal plots and also placed with the cereal during seeding. Plots were sprayed to control weeds. Forages were harvested in July, cereals were harvested in August, and yields for both crops were determined on a dry weight basis.

MONITORING ACTIVITIES

Several monitoring activities during each growing season were undertaken on a monthly or annual basis using standardized procedures. Soil fertility was determined each spring and used to establish fertilization rates. Soil moisture was monitored monthly, May to September, with a neutron probe, using one or two permanent access tubes per plot. Bulk densities were measured once during the growing season with a density probe, using the aforementioned access tubes. Soil sampling was conducted each autumn to determine soil salinity, soluble cations and anions, pH and saturation percentage on saturated extracts. Rainfall was monitored during each growing season with a gauge situated within the compound.

SUBSOIL DEPTH EXPERIMENT

Objective:	To determine the optimum depth of subsoil replacement over sodic mine spoil required to sustain agricultural capability.
Recommendation:	For forage production, 60 cm of subsoil over spoil is recommended. Given more time, it is expected that salts leached from the upper profile will accumulate below 60 cm at a concentration that restricts root growth, thus negating any advantage of deeper subsoil. When this happens yield would likely decline. To match average farm yields in the area, a replacement of 225 cm of subsoil would be needed, based on current findings. However, if subsoils could be reconstructed in a manner that increases moisture availability (less compaction and higher porosity) then a shallower subsoil thickness should be productive, comparable to

farm yields. Note that target farm yields represent a wide range of soil types, management practices, and climatic differences (data derived from Census Division statistics). Cereal yields were very low and are considered to be unacceptable. The minimum recommended thickness for subsoil based on cereal yield results is also about 60 cm, but better soil structure and reduced compaction are essental for successful reclamation.

Soil Salinity

Topsoils improved considerably over time as salts were leached downward. Upper subsoils improved slightly although there was some initial degradation as salts from topsoils were leached through. This slight improvement is limited to the upper 30 cm and should continue, but more time is needed to establish whether leaching continues to greater depths. Salt accumulation occurred below 30 cm to about 100 cm depth. In treatments with shallow subsoil (65 cm or less), this accumulation occurred in subsoils and spoils. In plots with deeper subsoil (135 cm or more) a second salt concentration zone occurred beginning 15 cm above and extending below the spoil interface. The accumulation beginning 15 cm above spoil is attributed to restricted leaching, or upward diffusion of sodium, or both.

Soil Moisture

Soil moisture levels were generally low, a reflection of the relatively dry climatic conditions. There was no evidence of perched or shallow water tables. Topsoils and subsoils were frequently quite dry to the approximate depth of crop rooting. In cereal plots, this was 30 to 40 cm whereas in forage plots, it was 120 to 140 cm, or 15 cm into spoil, whichever was shallower. Spoils tended to be moist but almost always below field capacity.

Soil Bulk Density

Topsoil densities appear to be normal for agricultural lands; however, subsoil densities are excessive (>1.70 g/cm^3). Probe measurements reveal declining soil densities over time; however, this is not confirmed by 1987 results of gravimetric sampling. Soil densities exceeding 1.45 to 1.55 g/cm^3 are known to severely restrict growth of many crops. Yield results imply that the cereals suffered much more than the forages.

Interactions

Considering crop yields, soil salinity and rooting patterns a minimum of 60 cm of subsoil is recommended at this time. If a shallower and more concentrated salt accumulation zone develops so as to preclude rooting beyond such a layer then this recommended minimum subsoil thickness may be reduced further. Also, improved materials handling to improve subsoil physical characteristics (better structure, reduced compaction, higher moisture supply) is essential to obtaining crop yields comparable to farmers yields in this region.

TORLEA SOIL EXPERIMENT

Objective:	To assess methods of reclaiming lands mined from areas of Torlea soils which are only suitable for perennial forage crops.
Recommendations:	All treatments with topsoil and subsoil over spoil were much better than topsoil over spoil or spoil alone, and Treatment 4 (50 cm B+C subsoil) is recommended from both a yield and salinity perspective. The surface ash amendment appeared to contribute to higher yields and better leaching of the upper profile.

Crop Yields

Forage yields on Treatment 1 (no topsoil nor subsoil) were essentially zero except very poor where ash was added. Treatment 6 (topsoil over 110 cm subsoil) yielded highest, however, the increase over Treatment 4 (topsoil over 50 cm subsoil) is not significant and does not warrant replacement of some 60 cm more subsoil. Surface ash amendments are clearly advantageous; however, problems associated with poor trafficability must be taken into account. Buried ash was detrimental to yields. Forage yields on the Torlea Soil treatments with subsoil were much higher than those of other experiments. This is attributed to more favorable physical characteristics.

Soil Salinity

Topsoils in Treatments 3 to 7 degraded from "Fair" or "Poor" initially, then improved to "Good" by 1986. Subsoils were "Unsuitable" throughout; however, upper subsoils in Treatments 4 and 6 were improving in latter years while those of other treatments were degrading. Ash and gypsum surface amendments helped to hasten soil improvement in the upper profiles, with ash being more effective.

Soil Moisture

All the topsoils and subsoils were frequently dry while underlying spoils were usually moist but below field capacity. The ash amended soils appeared to be drier than gypsum and control plots. This may be due to higher evapotranspiration from the ash plots which supported the best growth. Also there may be errors in calibration or in determining moisture retention limits due to the presence of ash such that the reported results underestimate soil moisture availability.

Soil Bulk Density

Torlea soils have much lower topsoil and subsoil bulk densities than observed in other experiments. The reason for this difference is thought to be due to handling procedures.

Root Distribution

In the Torlea plots there were plentiful roots to 50 to 60 cm in treatments with spoils below this depth. In shallower subsoils, rooting was limited by spoils. This depth of plentiful roots is greater than in other experiments and may be attributed to lower bulk density in spite of higher salinity and sodicity.

BOTTOM ASH EXPERIMENT

Objective:	To assess the potential of bottom ash as a capillary barrier to upward movement of sodium salts from mine spoil into replaced subsoil.
Recommendation:	There were no statistically significant (at $p = 0.05$) yield responses to buried gypsum or ash treatments although yields were highest where 45 cm of buried ash was applied versus the control. The buried gypsum or ash did not affect the quality of material; however, the ash enhanced leaching of spoil and increased the thickness of the rootzone (subsoil plus ash) and is therefore advantageous. Consideration should be given to using ash as a subsoil amendment, to enhance leaching, improve moisture storage, and permit a better rooting environment.

Crop Yields

Yield responses to treatments were not significant in statistical terms but forage yields increased with increased thickness of buried ash. This likely reflects increased root zone thickness and greater moisture supply.

Soil Salinity

Topsoils in all treatments improved from "Fair" in the first three years to "Good" afterwards. Improvement was slightly more pronounced under forages than cereals. Subsoil quality initially degraded then improved, ending at slightly higher EC, Na and SAR than original levels. The only evidence of effects of treatments on upward salt movement into subsoil is an increase of SAR in subsoil in Treatment 2 (buried gypsum layer). While the ash capillary barriers do not appear to be effective in governing subsoil quality, they do influence spoil quality as evidenced by declining spoil EC, Na and SAR with increasing ash thickness. In 1986, average SAR was 13, making subsoil "Unsuitable". Given more time and continuing leaching, it is expected that subsoils overlying the buried ash will improve. Such improvement in combination with the increased thickness of ash as a suitable rooting medium should contribute to significantly higher yields and better soils in the long term.

Soil Moisture

Topsoils and subsoils in Treatments 4 and 5 were usually dry under both cereals and forages, while in Treatments 1 to 3 cereals were moist more often. The ash layers appear to be dry but this may be due to errors in probe calibration with respect to readings in ash, or to errors in estimating average wilting point and field capacity, or to depth variations and consequent influences of subsoil and spoil on the readings.

Bulk Density

As in the Subsoil Depth Experiment, topsoil densities are normal but subsoil densities are excessive. The high subsoil densities are considered to be a major constraint to cereal rooting and productivity.

Root Distribution

The additions of gypsum and buried ash layers seemed to promote slightly deeper rooting (about 10 cm). Cereal roots generally ended above the spoil but forage roots were found to extend about 15 cm into spoil.

SLOPE DRAINAGE EXPERIMENT

Objective:	To determine the effect of degree of spoil levelling (slope) and aspect (north versus south) on salt movement and productivity of forages.
Recommendation:	There were significant yield responses to slope position such that lower slopes out-yielded upper slopes. Changes in soil quality in response to treatment occurred but are difficult to explain and no clear recommendation can be made. Note that in all positions there was no

evidence of groundwater or a perched water table, hence the sites should be considered to be representative of a groundwater recharge area.

Crop Yields

Only slope position had a significant effect on forage yields. All yields were below those observed in the other three experiments. This is attributed to different stand composition on the Slope Drainage Experiment rather than to soil or landscape limitations.

Soil Salinity

Initially, topsoils in lower positions had higher salinity and these improved over time along with upper and middle position topsoils such that all were "Good" in 1986. Slope position did not have much effect on other soil layers. Treatment effects occurred but are difficult to explain. Treatments 2 and 3 (10°N and 5°S) had higher salinity and sodicity in upper subsoils in 1985 and 1986 than Treatments 1 and 4 (5°N and 10°S). One possible reason is the side effects generated by runoff from the compound across lower positions of Treatments 2 and 3.

Soil Moisture

Topsoil and subsoil moisture contents were generally low but increased downslope, south aspects were drier than north aspects, and 10 degree slopes were drier than 5 degree slopes. Spoils were usually moist, but below field capacity, and there was no evidence of a shallow water table.

Bulk Density

Topsoil densities are normal but subsoil densities are excessive, averaging about 1.60 g/cm^3 in 1987.

Root Distribution

Forage roots were plentiful to about 60 cm, which is slightly deeper than in comparable Subsoil Depth plots. This may be partly due to differences in stand composition as well as to apparent slightly lower bulk density in Slope Drainage Experiments.

IMPORTANT FINDINGS ACROSS ALL EXPERIMENTS

1. Forage yields on Torlea Soil plots with subsoils, and the deeper (>165 cm subsoil) Subsoil Depth plots were good but forage yields on all other plots and all cereal yields were below those obtained by farmers in the region. Farm forage yields are based on Census Division statistics for Agricultural Reporting Area 4A, derived from about 100 farmers growing hay in the area.
2. Topsoil and subsoil are required for successful reclamation, based on soil salinity analysis. Current findings suggest that there should be 15 cm of topsoil (same as in natural soils) over at least 60 cm of subsoil for both cereal and forage production. To match farmer's forage yields, 225 cm of subsoil is needed but expected salt accumulation below 60 cm, due to leaching from above, will eventually restrict rooting and reduce yields. The problem then, is that subsoil physical properties above 60 cm must be improved to enhance rooting and increase moisture supply. The high yields on the Torlea plots with subsoil indicate that constructing soils with lower densities and implicit higher moisture availability could result in satisfactory yields with only 60 cm of subsoil. Improved subsoils should also permit cereal production.
3. Topsoils and upper subsoils have improved as a result of downward salt leaching. As of 1986, salts were accumulating below about 30 cm. More time is needed to establish the final depth and degree of salt concentration. In lower subsoils, there is evidence of upward movement (15 cm only) of sodium from spoil but there is also leaching of salts from subsoils into spoils. Again, more time is needed to establish the final equilibrium.
4. Amendments were more effective in increasing crop yields when placed on the surface than when placed above the spoil and bottom ash was more helpful than gypsum. However, trafficability is a limitation with the surface ash application.

5. Bulk densities of subsoils in the Subsoil Depth, Bottom Ash and Slope Drainage experiments were excessive, often over 1.70 g/cm^3. Research is needed on materials handling so as to improve physical characteristics of subsoils. Higher handling costs may be compensated by the need for a shallower depth of subsoil.
6. Saturation percentages declined significantly in the first couple of years in most treatments and soil layers. This is believed to be a reflection of lab technician judgement rather than real soil change. When adjustments are made to standardize saturation percentage and salt concentration, the significance and conclusions arising from current statistically significant findings may change. Generally, adjustments lead to a more favourable reclamation scenario. Without adjustments there appears to be a major increase of salts in the profile which is impossible in the absence of a water table near the surface. In future monitoring, more attention must be given to standardization of lab procedures in this regard.
7. The probe measurements of bulk density reveal apparent declines in density of topsoils and upper subsoils, and some increases or decreases in other layers. The declines in upper layers are not confirmed by gravimetric sampling. Fluctuations at greater depths are probably due to operational or calibration errors.

1. THE BATTLE RIVER SOIL RECONSTRUCTION PROJECT

1.1 INTRODUCTION

The Battle River Soil Reconstruction Project (BRSRP) involved establishment, soil and crop management, and research monitoring of four experiments designed to assess methods of reconstructing soil profiles following surface mining of coal in order to ameliorate the problems caused by the saline and sodic nature of the subsoils and bedrock in the Plains region of Alberta.

Experimental plots were constructed in 1980 on levelled mine spoil using mine machinery simulating the "take and put" system of mine reclamation.

The plan for the first phase of this research project was to manage the plots in a consistent, scientific manner for a five-year period. Plot work was initiated in 1981, but due to unsuccessful establishment of forages on most plots it was necessary to start again in 1982 and continue through to 1986. This report presents the research findings, interpretations, discussion, conclusions and recommendations based on data obtained during 1982-86.

The four experiments assess soil reconstruction methods in terms of soil materials, amendments and crops, as follows:

1. Subsoil Depth - varying subsoil depths, (ranging from 25 to 350 cm plus a control with no subsoil);
   - productivity of forage and cereal crops.
2. Torlea Soil - separating and mixing subsoil horizons, including different thicknesses;
   - use of gypsum and bottom ash as a surface amendment;
   - productivity of forage crops.
3. Bottom Ash - the use of bottom ash and gypsum as a barrier to salt movement;
   - productivity of forage and cereal crops.
4. Slope Drainage - manipulating the slope and aspect of reclaimed land;
   - upper, middle and lower slope positions;
   - productivity of forage crops.

Soil and crop husbandry practices applied on the plots were those determined to be normally used by farmers in the area, except that small machinery (40 horsepower tractor and matching implements) was used on the plots. Plot layout is shown in Figure 1.

The research component involved several major activities as follows:

1. crop growth, rooting depth and yield monitoring,
2. soil moisture monitoring,
3. soil bulk density monitoring,
4. soil sampling and salinity analysis,
5. rainfall and groundwater level monitoring from May to October,
6. statistical analysis of results and interpretation, and,
7. scientific reporting of activities and results on a quarterly and annual basis.

Conference presentations about the project were also given and summer field tours of the plots were made by several groups including farmers, land reclamation specialists, mining engineers, and agriculturalists (Leskiw 1984, 1987; Leskiw et al. 1986; Reid and Leskiw 1983b).

1.2 LITERATURE REVIEW

The main concerns about land reclamation, in areas of sodic spoil and solonetzic soils, at the time the experiments were designed focused on effects of soil depth, especially with respect to upward sodium migration; soil salinity and sodicity; slope and aspect. It was known that various soil amendments could be used but their effectiveness in this environment had not been tested. In this context, the set of four experiments was designed to examine these factors under cereal and forage crop production to represent the principal crops grown in this region. The experiments were established to be monitored at least five years to determine longer term effects on soil development and crop yield.

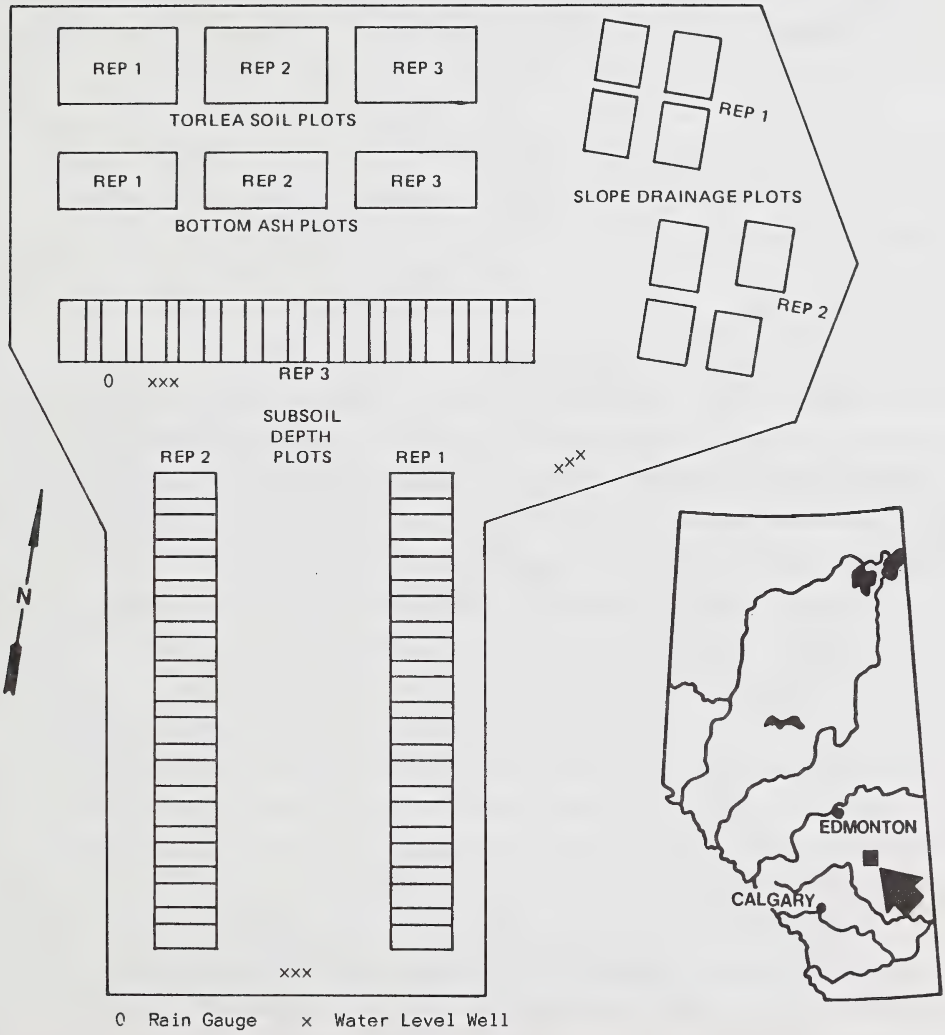

Figure 1. Project location and layout of experiments.

While this research was in progress there was on-going research at other locations, North Dakota being the prime example, having many similarities in soil and environmental conditions to those at Battle River. Results reported in the literature that are related to the experiments as originally designed as well as to special findings arising at the BRSRP plots are highlighted in this review.

First the inherent problems are identified; i.e., sodic spoil and solonetzic soil; then, factors affecting soil formation and soil forming processes are discussed; and, finally, management activities and their implications are addressed.

1.2.1 Sodic Mine Spoil

Sodic material presents major technical problems in reclamation of surface mined lands in east-central Alberta. Adverse chemical and physical properties of reclamation materials are further complicated by climatic and hydrogeologic conditions that result in water movement and salt migration. Restoring and sustaining land capability and productivity to pre-mined levels in this dynamic environment is complex and challenging.

The most popular method for ameliorating problems caused by sodic mine spoils was and continues to be the placement of good quality subsoil, topsoil, or both, above the mine spoil to provide a root zone with favourable chemical and physical properties. As little as 5 cm of topsoil over sodic spoil increases water infiltration rate, reduces runoff, and vastly improves plant survival and growth (Sandoval et al. 1973). Benefits of topsoil placement over spoil were well documented prior to 1980 (Dollhopf et al. 1977; Grandt 1978; Nielsen and Miller 1980; USDA 1977).

Soil depth required for adequate reclamation depends on environmental factors, intended land use and the nature of the spoil and soil materials. Soil thickness requirements for saline and sodic spoils may need to be greater than for other spoils to allow for upward salt migration, settling and subsidence, surface erosion, uneven spreading of soil material and internal drainage restrictions (Power et al. 1978a). Power et al. (1978b), in a North Dakota experiment, compared the first year growth of spring wheat, alfalfa, crested wheatgrass and native grasses on increasing depths of a productive silt loam topsoil and subsoil over sodic spoils (SAR = 26). They attributed the greatest benefit to topsoil replacement. Yields of all vegetative types increased as total thickness of replaced soil (topsoil plus subsoil) increased, to a depth of 70 cm where crop yields were comparable to those of unmined lands. Additional yield increases with greater depth of soil were not encountered. The sustainability of such productivity was not evaluated at that time.

In a review of topsoil management on mined lands, Schuman and Power (1981) stated that the depth of topsoil used must be determined by the quantity available and the quality of subsoil and spoil. They contended that no benefits would be gained by topsoil depths greater than 100 cm.

The migration of salts from the sodic mine spoil into the soil materials was a major concern of reclamation in the Great Plains Region at the time the BRSRP was established. Initial benefits from topsoil and subsoil placement over spoil could be lost if yields would be eventually affected by salt migration upward. Merrill et al. (1980) documented changes in soil salinity and sodicity following reclamation due to diffusion into the soil over an eight year period. They found that most of the movement occurred in the first 2 years after which the gradient was reduced and salt movement began to stabilize.

1.2.2 Solonetzic Soils

Such soils are common in the coal fields of the Alberta plains where the bedrock of the coal bearing formations occurs close to the surface. Reclamation of lands with extensive areas of Solonetzic soils is difficult, because these soils often have very thin A horizons making salvage of suitable quantities of topsoil a problem. Furthermore, the subsoils are commonly shallow and have undesirable characteristics resulting from the accumulation of clay and sodium in the Bnt horizon (Toogood and Cairns 1973). Additional management must be employed to improve subsoil quality. During stripping of soil materials prior to mining, the sodium enriched B horizon can be mixed with the calcium enriched upper C horizon for replacement over the spoil during reclamation.

Studies of Solonetzic and Chernozemic soils in several plot experiments aimed at restoring strip mined lands to their original productive capability have been monitored over a number of years in central Alberta. Six years of results from the Camrose Ryley Project (TransAlta Utilities Corporation and Fording Coal Ltd. 1987) are now completed. Two wedge experiments set up in test pits were aimed at examining the performance of reclaimed Solonetzic and Chernozemic soils with varying depths of subsoil. Solonetzic subsoil varied in depth from 0 to 100 cm while the Chernozemic subsoil ranged from 0 to 240 cm. Topsoil was replaced over half of each plot, and two crop rotations were grown. It was concluded that 15 cm of topsoil and 55 cm or more of subsoil replaced over spoil were sufficient for successful reclamation.

1.2.3 Salt Movement

Leaching from surface materials into the lower soil profile occurs wherever rain and surface water percolate through the soil, carrying soluble salts with it. Except where a shallow groundwater table exists, as in a groundwater discharge situation, a general improvement in the quality of saline and sodic surface materials will occur due to the downward movement of salts.

Both saturated and unsaturated percolation into and through a soil can occur. Where rainfall is sufficient, saturated flow through the soil will occur, with the wetting front proceeding at a uniform rate through the soil, provided materials are uniform. Where surface fissures and cracks are common, unsaturated flow down them can occur. Halvorson (1985) reported increases in sodium to an average depth of 38 cm below the soil-spoil interface, indicating that Na had been leached out of the upper part of the profile. More than seventy sites in North Dakota, reclaimed for more than 10 years, were sampled.

Richardson and Farmer (1982) found that SAR values had decreased, from 12 to below 3, in surface materials of sites in southeastern Montana reclaimed for 5 to 7 years. A progress report on research and reclamation of strip mined lands, prepared by the North Dakota Agricultural Experiment Station (USDA 1979), reported downward leaching of salts to depths of 60 to 90 cm in North Dakota.

Similar downward leaching of salts has been reported in a number of studies from the U.S. Northern Great Plains and Western Canada, for example Stark and Redente (1986) in Colorado, and Moran et al. (1987) in Alberta.

Following reclamation, upward migration of salts from saline and sodic spoil into good quality overlying soil material has also received much attention. Initial benefits from topsoil and subsoil placement over spoil can be lost as yields eventually can be affected by upward salt migration. Several mechanisms are likely responsible for this phenomenon, including capillarity, diffusion and convection.

Upward movement of soil water and soluble salts by capillarity will occur above the water table to a height dependent upon pore size and continuity. Where water tables, either permanent or temporary, are shallow enough to allow sufficient height of capillary rise into the rooting zone, there can be an increase in soil salt content to a point where plant growth is affected. In central Alberta, Moran et al. (1987) found that salt movements within reconstructed soil profiles were largely dependent on the presence of a shallow, permanent groundwater table. Where the water table occurred within 1.0 m of the soil surface, soils could be expected to become saline and sodic. Where water tables were deeper, downward leaching of salts predominated.

Upward diffusion of salt across a chemical gradient has been presented as an alternate mechanism of upward salt migration (Merrill et al. 1983a). To be effective, a salt concentration gradient must exist along which diffusion can take place, that is, salts moving from zones of high to low concentrations. At the Battle River site, such a gradient occurs wherever sodic spoil is overlain by better quality subsoil or topsoil.

Convective flow of soil water as a result of evaporation is another potential mechanism of upward movement of salts in soil water solutions. In a situation such as the Battle River site, where rainfall tends to occur as major isolated events, followed by very dry periods, convection could be an important mechanism of upward salt migration.

Diffusion and convection as mechanisms of upward salt movement in reclaimed soils were studied by Merrill et al. (1983a) in laboratory column studies. The researchers concluded that salt diffusion was a significant mechanism of sodium accumulation in soil where soil materials were strongly dispersed and a salt concentration gradient existed. Very low hydraulic conductivity of spoil materials restricted salt transfer by convective flow. Results of this study were then applied to several field situations. From these it was concluded that significant sodium accumulations did occur by diffusion when a sufficiently large chemical gradient between soil materials and spoil existed. A very low hydraulic conductivity of materials was also necessary to prevent removal of accumulated salt by leaching. It was considered unlikely, however, that Na could be carried higher than 10 to 15 cm upward into non-sodic materials.

Upward salt migration has been reported in a number of studies. In Colorado, Barth (1983) and Barth and Martin (1984) found that sodium had migrated from 7 to 14 cm upward into overlying soil on sites reclaimed for 4 years. Similarly, in North Dakota, Merrill et al. (1980) reported upward migration of salts into the soil over an eight-year period. Most of the movement occurred in the first 2 years after which the gradient was reduced and salt movement began to stabilize. Similar upward movement of salts on reclaimed sodic mine spoils has been recorded by Merrill et al. (1983b). In Alberta, upward salt migration has been recorded on some treatments of plots monitored for the Highvale Soil Reconstruction Project (Monenco Consultants Ltd. 1987).

1.2.4 Water Use and Movement

In areas where water limitation is the main constraint to crop growth, crop yields will increase to the degree that water available to plants is increased. Yields become a function of total available water and nutrient availability within the root zone of the reconstructed soil (Merrill et al. 1985). At the Battle River Site where water is limiting to crop production in at least 50% of years (Bowser 1967), soil-water and plant relationships are of vital concern.

A number of water use related studies have been carried out, mainly in the western United States. Studies on reclaimed sodic mine spoils in North Dakota probably relate most closely to the situation at the Battle River Site, as both soil materials and climatic conditions are similar. Moisture levels were monitored by neutron probe from 1974 to 1981 on spoils re-levelled and re-vegetated in 1972 in North Dakota, to examine soil water changes over time on reclaimed spoil compared to undisturbed sites (Schroeder 1983). Over that period, average total soil water decreased in soils due to increased vegetation growth and below normal yearly precipitation over most of the period. Soil water recharge during non-growing periods was correlated to factors affecting infiltration capacity or snow entrapment.

Merrill et al. (1985) measured water movement, water use and root growth for 3 years on Western North Dakota soils reconstructed with sodic (SAR=30) mine spoils overlain with varying thicknesses of subsoil and topsoil. In general, soil water depletion increased as subsoil thickness increased. This reflected an increase in water use efficiency with an increase in soil thickness.

Water recharge and depletion characteristics also varied with soil depth to spoil. For example, comparing the 0.25 m subsoil treatment with the 1.0 m treatment, soil water recharge and depletion characteristics at 0.15 m depth were similar on both. At 0.45 m depth, the 1.0 m subsoil treatment showed a large net depletion while there was little variation on the 0.25 m treatment. At 0.75 m depth, the 1.0 m treatment still showed a net depletion while a slow recharge occurred on the 0.25 m treatment. Merrill et al. (1983a) speculated that recharge is chiefly driven, despite low hydraulic conductivity, by thermal gradients, and consists of vapour and mixed liquid-vapour fluxes.

1.2.5 Soil Compaction

Compaction causes soil bulk densities to increase and this affects soil-water-plant relationships in several ways. Total pore space is reduced along with aeration porosity and volumetric moisture content. Larger macro pores become reduced in number and size, while smaller micro pores become more numerous. Water infiltration and hydraulic conductivity are decreased. Water holding capacity, particularly in medium textured soils may actually increase with compaction (Halvorson et al. 1980; USDA 1979). However, water contents at wilting point are higher, and at field capacity lower, due to the predominance of micro over macro pores. The end result is a decrease in the volume of water available to plants. In areas already somewhat deficient in moisture like the Battle River site, this can be critical.

Increasing compaction and bulk densities can seriously affect plant root growth, further reducing the volume of water available to plants. Jones (1983), for example, found that a clear relationship between soil bulk density and the prevention of root growth did not exist. Rather, it proved to be a function of soil texture and soil water content along with bulk density.

Increases in bulk densities on reconstructed mined lands compared to pre-mine or undisturbed conditions appear to be commonplace. For example, Wollenhaupt (1985) working in North Dakota, found bulk densities on reconstructed mined soils to be higher than on similar undisturbed soils with increases of up to 20% recorded, to nearly 1.7 g/cm^3. Also, decreased plant available water capacity and hydraulic conductivity were observed, but these conditions did not appear limiting to root penetration. Pedersen et al. (1980) reported bulk densities of up to 1.76 g/cm^3, on reconstructed minespoils in Pennsylvania. Like Wollenhaupt, they found decreases in hydraulic conductivity, infiltration and water retention. Similar results were reported by Indorante et al. (1981) in southern Illinois.

Bulk densities as high as 1.9 g/cm^3 have been recorded at the Battle River site, similar to those reported by Silburn and Crow (1984) in Oklahoma. They found total available water to be decreased in reclaimed soils to 60 to 85% of that in comparable undisturbed soils.

Greenhouse pot experiments have produced similar conclusions concerning the detrimental effects of excessive soil compaction. A study by Stucky and Lindsey (1982) showed that yields of soybeans decreased with increased compaction from bulk densities of 1.4 g/cm^3 to roughly 1.6 g/cm^3. Sundstrom et al. (1982) noted an increase in root and shoot mass of beans in growth chamber studies as bulk densities decreased from 1.55 g/cm^3 to 1.40 g/cm^3.

Persistence of compaction on reconstructed soils is an important issue. If high bulk densities could be reduced over a few years of wetting-drying and freezing-thawing cycles, soil compaction would not be considered a problem. Unfortunately, current evidence does not support this.

Schafer and Nielsen (1979), in a study of reclaimed Northern Great Plains strip mines 1 to 50 years old, found that compaction significant enough to affect water movement had persisted for at least 50 years at one site. Iron ore spoils 70 to 130 years old in West Virginia had not yet developed bulk densities as low as natural undisturbed soils (Smith et al. 1971).

In Ontario, Kay et al. (1985) found that freeze-thaw cycles did not reduce bulk densities of soils compacted under zero-tillage operations, despite the formation of extensive ice lenses in the soils. In another Ontario study, it was found that severe compaction (densities greater than 1.4 g/cm^3) on clayey soils reduced yields by some 25% (Can-Ag Enterprises 1988). Nearer the Battle River site, changes in bulk density with time were recorded by Moran et al. (1987) as part of the Plains Hydrology and Reclamation Project. They found that bulk densities were highest for any given depth in April, declined through May to August, and then increased in September and October. There appeared to be a gradual decrease in overall bulk density over 2 years of monitoring.

At Highvale Mine in Alberta, subsoil bulk densities for forage subplots were significantly lower than those of cereal plots to a depth of 1.5 m after 4 years. The extensive rooting system of the alfalfa component of the forage was considered responsible for the reduction in subsoil bulk density (Monenco Consultants Ltd. 1987).

Soil strength as measured by penetration resistance appears to be closely related to ease of root penetration of a soil (Taylor and Gardner 1963), regardless of moisture content. This was confirmed by Thompson et al. (1987) on non-sodic mine spoils in Illinois. They found a high correlation (r^2=0.73) between penetrometer resistance and root system development, although the correlation between bulk density and root growth was slightly higher (r^2=0.81).

1.2.6 Soil Structure

Massive soil structure like that which occurs during strip mining operations and subsequent soil reconstruction has detrimental effects on the natural structure of the soil developed over centuries of pedogenic process. Poor structure coupled with the high sodium contents and SAR values of spoil and some soil materials used in reclamation in areas like the Battle River Site, results in restored soils tending to be massive and highly dispersed. Like increased compaction, loss of soil structure seriously affects soil-water-plant relationships. Infiltration and hydraulic conductivity both decrease as soils become more massive and dispersed. Roots normally penetrating along fissures and cracks are restricted in their development.

Potter et al. (1988) examined physical properties of soils 4 and 11 yr after reconstruction, in North Dakota. Soils reclaimed using similar methods and with similar vegetation histories were compared to each other and to an equivalent undisturbed soil. They found that bulk density was greater in the reclaimed soils; that macropore volume was lower than in undisturbed soils but it increased with time; and that micropore volume was similar in topsoils but greater in reclaimed subsoils. Saturated hydraulic conductivity of reclaimed topsoil and subsoil was 25% and 10%, respectively, of that of undisturbed soil, and did not differ between the 4 and 11 yr sites. Reduced permeability was attributed to increased bulk density and disruption of soil structural units and pores during mining and reclamation.

Several workers have examined soil structure on reclaimed mine soils, and its relationship to water and root penetration, and plant growth. The importance of sodium content on soil structure was emphasized by Gee et al. (1976) in characterizing sodic and non-sodic materials. Where SAR levels were greater than 20, over 50% dispersion occurred with a reduction in number and size of stable aggregates. Strong crusting, limiting to plant growth, occurred wherever surface SAR exceeded 10.

The relationship between root penetration and soil structure on non-sodic soils has been studied by Jones (1983), using published and unpublished data on root growth in natural soils with compacted horizons. These results suggest that observed restriction of root penetration may be due to the disruption of natural soil structure, as well as an increase in bulk density. McSweeney and Jansen (1984) studied rooting behaviour of reclaimed non-sodic mine spoils in Illinois. They found that roots easily penetrated reclaimed materials made up of aggregates loosely compressed with extensive continuous void spaces, despite surface compaction. Massive subsoils, regardless of bulk densities, did not promote root growth. Roots tended to be shallow, and restricted to desiccation cracks. They concluded that certain soil construction operations could promote better soil structure. Specifically, operations using a mining wheel in combination with belt transportation favour the formation of a more desirable fritted structure (rounded aggregates loosely compressed together). Operations using scrapers exclusively favour the formation of less desirable massive conditions.

Several studies have been undertaken to examine root distribution on soils reconstructed from sodic minespoil, chiefly in North Dakota. Gee et al. (1976) carried out detailed physical analyses of reclaimed mined lands, examining bulk densities, soil structure and water movement characteristics. They found bulk densities to be similar to unmined soils but soil structure to be highly dispersed due to high sodium levels. Water movement and retention were greatly affected by the sodic characteristics of the spoil.

Also in North Dakota, Gilley et al. (1982) examined differences in root distribution between undisturbed soil, non-sodic (SAR=5) and sodic (SAR=37) spoil. Only the sodic spoil levels restricted root growth. Halvorson et al. (1980) reported similar root restriction on soils also reconstructed from sodic mine spoil in North Dakota.

1.2.7 Topography

Several researchers have studied effects of topography on reclamation in the North Great Plains. Topographic effects on depressional storage of water, infiltration and erosion were discussed by Gardner and Woolhiser (1978). Sinai et al. (1981) studied in detail the effect of surface curvature on moisture movement and crop yield. These researchers postulated that lateral moisture flow occurs even under unsaturated soil conditions, and is encouraged by non-conforming layers in the soil (e.g., the soil/spoil interface). Yields were higher in concave landscape positions where moisture, probably carrying nutrients, accumulated. Wollenhaupt and Richardson (1981) documented the same relationship between landscape position, soil moisture, and crop yield.

In reclamation situations involving saline and sodic spoils near the surface, groundwater carrying a high amount of dissolved salts could result in a discharge situation in the concave (lower slope) positions. The benefit of increased water content in these positions may be eventually negated by salinization. The effect of aspect on evaporative demand could be an important factor in bringing soil moisture and salts to the surface as discharge. Factors causing dryland salinity through the recharge and discharge processes in natural landscapes were well documented (Vander Pluym 1978), but further study was needed in reclaimed areas.

Studies were conducted in North Dakota to observe crop productivity and water use as a function of subsoil quality and depth, and their interaction with topographic position in topsoil-subsoil-minespoil profiles (Merrill 1983). The results demonstrated that soil quality factors, climate and topography all interact in a complex way to affect productivity. Yields increased with soil depths to maximum values at sideslope positions. Yields were lowest at top slope positions. Topographic position, however, affected wheat yields considerably less than forage yields.

1.2.8 Soil Depth

Studies in the Northern Great Plains under environmental conditions and reclamation practices similar to those at the Battle River site revealed that optimum crop yields were obtained at total soil depths (topsoil and subsoil) of 70 cm to 120 cm (Barth and Martin 1984; Hargis and Redente 1984) or at subsoil depths of 70 cm covered by 20 cm of topsoil (Power et al. 1981; Schuman and Power 1981). Yields were observed to decrease when total soil thickness over spoil exceeded 150 cm. Under adverse growing conditions such as spring drought, yields of forage grasses were low and little affected by subsoil materials (Merrill et al. 1982).

Doll et al. (1984) presented a review of reclamation research being carried out at the Northern Great Plains Research Centre in North Dakota. In a wedge experiment near Stanton, North Dakota, sodic spoils were levelled, then relatively good quality subsoil (B and C horizons) was spread in a wedge-shaped configuration over the sodic spoil (SAR > 20), increasing in thickness from 0 to 215 cm. Topsoil was then spread over subsoil at 0, 20 or 60 cm thicknesses. At least 20 cm of topsoil was required to maximize yields. Topsoil replaced over 60 cm of subsoil produced even higher yields. Highest yields of all were obtained at total soil depths of 90 to 130 cm.

The Zap Double Wedge Experiment was initiated in 1975 at the Indianhead Mine near Zap, North Dakota. Twenty-five centimetres of topsoil was uniformly placed over three subsoil materials which differed in salinity, sodium content and texture. Highest yields of crested wheatgrass were obtained on soil thicknesses of 50 to 80 cm and highest spring wheat yields were on soil thicknesses of 40 to 110 cm.

Based on these experiments, Doll et al. (1984) suggested some guidelines for soil depth replacement, summarized in Table 1. They cautioned however, that these guidelines were developed based upon experiments which had been monitored for relatively short periods of time (about five years) and that movement of soluble salts and sodium, and changes in soil physical properties need to be more precisely described over the long term.

Water movement within reconstructed soils appears to be greatly affected by depth of subsoil replacement. Merrill et al. (1985), in North Dakota, found that forage yields were 2 to 3.5 times greater on 1.0 m soil thicknesses compared to 0.25 m. Even though roots were able to penetrate spoils so that root weight densities were similar on spoils and subsoils at the same profile depth, root water uptake was much less from the spoil. Low hydraulic conductivity in spoil materials, resulting in less use of stored water, was considered the main cause.

At Highvale Mine, soil reconstruction subsoil depth plots have been monitored since 1982 (Monenco Consultants Ltd. 1987). Five depths of non-saline, non-sodic subsoil (0, 0.55, 0.95, 1.35, 1.85 and 3.45 m) were replaced over sodic minespoil. All plots were topsoiled. Over five years, average forage yields were significantly different between the 0.0 m and the

Table 1. Suggested guidelines for soil replacement based upon spoil properties (North Dakota).

Spoil Properties			Depth of Soil Replacement		
Texture	EC mS/cm	SAR	Topsoil	Subsoil	Total
			cm		
Coarse[a]	<6	<12	30	60 to 75	90 to 105
Medium[b]	<6	<12	30	30 to 45	60 to 75
--[c]	--[c]	12 to 20	30	60 to 90	90 to 120
--[c]	--[c]	>20	30	90 to 120	120 to 150

[a] Sandy loam or coarser

[b] Loam or finer

[c] Not applicable, SAR dominant property

0.55 m and deeper subsoil treatments. Yields were highest on the 0.95 m treatment but they were not significantly different from those on other treatments with subsoil. Cereal grain production was significantly less on the 0.0 m treatment compared to any treatment with subsoil.

1.2.9 Soil Amendments

Various chemical amendments containing calcium can be applied to remove the sodium from the soil colloids and improve the soil's physical characteristics. Two types of amendments are commonly used: soluble calcium salts including gypsum and calcium chloride, and calcium compounds of low solubility (e.g., limestone).

Soluble calcium salts are most effective under the dryland conditions of the Northern Great Plains. Gypsum has been applied with varying degrees of success to sodic strip-mined spoils. Dollhopf and DePuit (1981) found no significant effects of incorporated gypsum after 3 years of monitoring reclaimed mine spoil in Montana. Merrill et al. (1983b), reported results of a study of the reclamation techniques of topsoil overspreading, gypsum application, and multi-year fallowing applied to mine spoils ranging in quality from non-sodic to highly sodic, at four locations in North Dakota. Gypsum incorporation increased average yields by 19% on topsoiled, highly sodic spoil (SAR = 30). Soil water depletions and recharges were significantly higher, and the sodicity of highly sodic topsoiled spoils was decreased by up to 25%.

Calcium rich ash from the coal burning thermal power stations in Alberta was considered to have potential for use as a soil amendment on sodic soils (Lutwick et al. 1981). McCoy et al. (1981) analyzed bottom and fly ash from four power stations in Alberta and found that ashes from Battle River and Sundance Power Plants have potential as a low grade lime material or as an ameliorative source of calcium in slightly sodic soils. Shaneman and Logan (1978) determined that a 15 cm layer of bottom ash contains an exchangeable calcium content roughly equivalent to 20 t/ha.

Lutwick et al. (1981) showed that surface incorporated bottom ash reduced the crusting tendency of sodic soils as measured by modulus of rupture. The application of bottom ash over the surface of reclaimed lands increases the water holding capacity and can result in a better medium for crop growth than sodic spoil. However, poor traction hampers field operations until a crop is established (Natsukoshi 1981).

Both chemical and physical amendments have received considerable attention since 1981. In Alberta, gypsum was applied as an amendment to trial plots of the Camrose Ryley Project (TransAlta Utilities Corporation and Fording Coal Ltd. 1987). After 10 years, topsoil salinity had increased, sodicity decreased, and average crop yields were not affected.

Results of the Bottom Ash Trial Plots, set up adjacent to the BRSRP site at Vesta Mine, are now available (Fullerton 1987). Bottom ash was applied at thicknesses of 10, 20 and 30 cm, and was incorporated using a disc, chisel plow or Kellough Subsoiler, or left as a blanket on the surface of the spoil. The 30 cm rate was the most effective in promoting growth. Forage yields were higher than those reported for local farms. Subsoiling proved to be the best method of incorporation. Although phytotoxic levels of plant-available boron occurred in soils, plants did not show any toxicity symptoms. Even though ash appeared to stabilize over time, trafficability remained a problem on the 30 cm plots.

1.2.10 Barriers

Redente et al. (1982) working in northwestern Colorado, tested the use of gravel and cobble as a capillary barrier between a good quality topsoil and retorted oil shale having electrical conductivity of 7 mS/cm and SAR of 14. The capillary barrier enabled topsoil depths to be reduced from 90 to 60 cm without a reduction of forage growth. However, the filling of capillary pores with topsoil particles was observed after 3 years. This could effectively reduce the long term benefits of the capillary barrier.

In a more recent paper, Stark and Redente (1986) reported no upward migration of trace elements or salts by diffusion or capillarity through a 30 cm rock capillary barrier in Colorado over six years. Buried ash between spoil and subsoil was considered to be a useful barrier to sodium movement in that the coarse, sand-like ash would act as a capillary barrier. Its high calcium content may provide a potential buffer against sodium movement (Parker 1981). The chemical analysis and potential uses of fly and bottom ashes were described by others (Lutwick et al. 1981; McCoy et al. 1981). Water must be under zero suction (pressure) before it can move from the fine textured spoil into the large pores of a capillary barrier which does not exert suction on the water. Therefore, water should only move into the coarse capillary barrier after saturation has occurred in the fine textured mine spoil (Buckman and Brady 1969). If the mine spoil and the capillary barrier became saturated, then water and salts would be readily transmitted from the mine spoil into the plant root zone. Such conditions would be expected in areas of shallow water tables, for example, in groundwater discharge areas.

Gardner and Woolhiser (1978) briefly discuss the role of subsoil layering in manipulating the hydrological cycle and the movement of soluble salts by: increasing the depth to toxic salts; creating a compacted slowly permeable layer to limit downward water movement; or using a coarse layer to restrict upward water flow by capillary movement.

1.3 PROJECT SETTING

1.3.1 Climate

Climate is one of the major factors governing crop yields and also salt migration in soils. The project area experiences a continental climate characterized by warm summers and cold winters. January is the coldest month with a mean temperature of -16° C and July is the warmest month with a mean temperature of 17° C.

The agroclimatic class is 2AH indicating slight moisture and heat limitations (A.S.A.C. 1987). There is adequate precipitation (400 to 450 mm annually) and a long enough frost free period (averaging over 90 days) to permit the growing of all dryland crops that are typical to the prairie region of western Canada. The relatively low annual precipitation at the Forestburg Plant Site (Table 2) is partially due to its lower elevation along the Battle River.

Table 2. Precipitation at the Forestburg Plant Site and Battle River Soil Reconstruction Project.

	May	June	July	August	September	Growing Season (Total)
	mm					
20-year Average FPS[a] (1967 to 1986)	45.3	77.0	71.5	53.4	42.1	289
5-Year Average FPS (1982 to 1986)	44.5	71.9	88.0	55.1	54.7	314
1982	56.8	46.6	135.9	93.9	44.8	378
1983	55.2	147.3	70.7	20.6	24.2	318
1984	22.2	80.1	23.0	36.6	117.8	280
1985	65.0	39.1	60.7	99.9	21.4	286
1986	23.4	46.6	149.8	24.6	65.3	310
4-Year Average FPS (1983 to 1986)	41.4	78.3	76.0	45.4	68.4	310
4-Year Average BRSRP[b] (1983 to 1986)	32	66	58	42	48	246
1983	43.5	133.0	60.5	19.0	19.5	276
1984	15.0	67.0	26.5	38.0	104.0	250
1985	57.5	36.5	50.0	98.0	17.0	258
1986	12.0	27.5	93.3	15.3	52.4	200

[a] FPS - Forestburg Plant Site (Environment Canada)

[b] BRSRP - BRSRP Compound (Alberta Research Council)

Precipitation data are available from Environment Canada for the Forestburg Plant Site, for the 20-year period 1967 to 1986. Growing season (May to September) 20-year averages are compared to averages for the 4 and 5-year study periods (1982 to 1986) in Table 2. Five-year monthly averages are very close to 20-year averages except for September which was slightly wetter than long-term averages. Typically, rainfall occurs sporadically throughout each month, with two major rainfall events accounting for an average of nearly 60% of total monthly rainfall over the 5-year study period. This has important ramifications for crop production, since the timing of a single major rainfall event often is critical for crop growth.

In addition, since 1983, Alberta Research Council has been monitoring precipitation within the BRSRP compound, with a temporary climate station. Monthly results during the growing season and four-year averages are also given in Table 2. Precipitation averaged 60 mm less at the BRSRP compound throughout the growing season, compared to Forestburg Plant Site averages. Monthly comparisons indicate May and June each received about 10 mm less while July and September each had 20 mm less.

1.3.2 Physiography and Geology

The study area falls within the Castor Plain Physiographic District (Pettapiece 1986), an area of morainal veneer and blanket overlying areas of undulating bedrock of the lower Horseshoe Canyon Formation. Horseshoe Canyon Formation materials which occur above coal seams are very saline, sodic and high in clay, and are generally rated "Unsuitable" for reclamation.

Soils have generally formed on glacial till overlying Horseshoe Canyon Formation materials at varying depths to five metres. In places, overlying glacial till has eroded, exposing bedrock to the surface (Maslowski-Schutze et al. 1986).

1.3.3 Soils

The area is dominated by Orthic and Solonetzic Dark Brown Chernozemic soils, Dark Brown Solodized Solonetzic soils and intergrades of these. Where soil parent materials are glacial till, Flagstaff Series (Solonetzic Dark Brown Chernozem), and Halkirk Series (Dark Brown Solodized

Solonetz) soils predominate. Where residual materials are found at or near the surface, soils of the Torlea Series (Dark Brown Solodized Solonetz), typical of the soils from which the Torlea Experimental plots were constructed, occur (Wells and Nikiforuk 1988).

Typical soil profile descriptions for the Halkirk and Torlea Series are presented in Tables 3 and 4.

1.3.4 Agriculture and Land Use

Arable soils in the region are used for dryland crop production, mainly wheat, barley and canola; non-arable lands are utilized for pasture and forage production.

Crop yields specific to the area near the BRSRP location are scarce, since most available data are reported on a Crop District, or Agro-ecologic Unit basis in summary form. A number of sites on Solonetzic soils in Flagstaff and Paintearth Counties were studied to evaluate deep plowing, ripping, and liming feasibility, from 1982 to 1986 by the Soils Branch, Alberta Agriculture. Crop yields from a number of these trials, near the BRSRP study site, and from regional records are compiled in Table 5, based on file information provided by Alberta Agriculture.

1.4 PLOT CONSTRUCTION

Construction of plots and material sampling to determine baseline chemical characteristics were the main activities during 1980. Techniques employed in constructing the experiments simulated the "take and put" technique of mine reclamation as much as possible, as described by Grandt (1978). First, the area of mine spoil was levelled, then plots were constructed using Manalta Coal Ltd. - Vesta Mine machinery (dozers and scrapers). Construction involved first excavating the levelled spoil to make a trench meeting plot dimensions for width, length and depth (land surface to spoil). Then subsoil material was hauled in to meet depth requirements plus a little extra to compensate for anticipated settling. Finally, 15 cm of topsoil was placed uniformly over the subsoil.

Table 3. Profile description - Dark Brown Solodized Solonetz, Halkirk Series.

HALKIRK SERIES

Classification: Dark Brown Solodized Solonetz

Parent Material: Weakly calcareous, moderately saline, clay loam till.

Horizon	Depth, cm	
Ap	0 to 11	Very dark grayish brown (10YR 3/1.5 m); sandy loam; moderate, medium cloddy and weak to moderate, fine to medium granular; very friable; abundant, very fine, random roots; abrupt, smooth boundary.
Ahe	11 to 18	Brown (10YR 4/2.5 m); sandy loam; weak, fine, granular; very friable; plentiful, very fine, random roots; clear, smooth boundary.
Ae	18 to 19	Light yellowish brown (10YR 6/3 m); sandy loam; very weak, fine granular; friable; plentiful, very fine, random roots; abrupt, smooth boundary.
Bnt	19 to 37	Very dark grayish brown (10YR 3/1.5 m); clay loam; strong, coarse columnar breaking to weak, medium, angular blocky; very firm; continuous, thick clay skins in all voids or channels and on vertical and horizontal ped faces; few, very fine, vertical, exped roots; clear smooth boundary.
Ccas	37 to 50	Brown (10YR 5/3 m); loam to clay loam; weak, coarse prismatic; firm, weakly saline; weakly calcareous; few, very fine, vertical, exped roots; clear, smooth boundary.
Csak	50 to 67	Dark brown (10YR 3.5/2.5 m); loam to clay loam; weak, coarse prismatic; firm; strongly saline; weakly calcareous; very few, very fine vertical, exped roots; clear smooth boundary.
Csk	67 +	Dark brown (10YR 3/2.5 m); clay loam; weak, coarse prismatic; firm; weakly saline; weakly calcareous; no roots.

(from Wells and Nikiforuk 1988)

Table 4. Profile description - Dark Brown Solodized Solonetz Torlea Series.

TORLEA SERIES

Classification: Dark Brown Solodized Solonetz

Parent Material: Weakly calcareous, moderately to strongly saline, clay loam to clay residual materials (weathered sodic shales and sandstones) or on thin till of similar composition overlying these residual materials.

Horizon	Depth, cm	
Ap	0 to 11	Dark brown (10YR 4/3 m); silt loam; weak, coarse cloddy and weak to moderate, fine granular; friable; abundant, very fine and fine, random inped and exped roots; abrupt, smooth boundary; 10 to 12 cm thick; moderately acid.
Bnt	11 to 28	Very dark brown (10YR 3/2 m); clay loam; weak to moderate, very coarse columnar breaking to moderate to strong; medium, angular blocky; very firm; continuous, thick clay skins in all voids or channels and on vertical and horizontal ped faces; plentiful very fine, random exped roots; clear, smooth boundary; 14 to 19 cm thick; moderately alkaline.
Csa	28 to 48	Very dark gray (10 YR 3/1 m) and dark grayish brown (10YR 4/2 m); clay loam; moderate very fine to fine, angular blocky; firm; strongly saline; few, very fine, random, exped roots; clear, wavy boundary; 10 to 22 cm thick; moderately alkaline.
IICsaca	48 to 55	Dark grayish brown (10YR 4/2 m); sandy clay loam; weak fine to medium pseudo platy; firm; strongly saline; weakly calcareous; very few, very fine, vertical roots; clear, wavy boundary; 3 to 10 cm thick; strongly alkaline.
IICs	55 +	Pale olive (5Y 6/3 d); common, medium, distinct (5Y 6/6 d) mottles; loam to clay loam; weak, fine to medium pseudo platy; firm; weakly saline; no roots; strongly alkaline.

(from Wells and Nikiforuk 1988)

Table 5. Wheat and forage yields from agricultural lands and plot studies for comparison with BRSRP yields, 1982 to 1986.

Wheat (kg/ha)	Mean	1982	1983	1984	1985	1986
Undisturbed Control[a]	1556	2117(5)[b]	1313(6)	1039(7)	1280(7)	2030(5)
3 Layer Plow[a]	2358	--	1581(2)	1809(2)	3176(1)	2868(1)
Regional[c]	2061	2353	2043	1735	1802	2372
Torlea - Paintearth[d]	1569	1977	1171	--	1435	1694

Forages (kg/ha)	Mean	1982	1983	1984	1985	1986
Undisturbed Control[a]	1587	1838(1)	1682(1)	1457(1)	1525(2)	1535(3)
3 Layer Plow[a]	2542	2803(1)	2959(1)	1726(1)	2915(1)	2309(2)
Regional[c]	3225	3360	3360	2912	2688	3808
Torlea - Paintearth[d]	1276	890	1117	676	2242	1456

[a] Yields from Solonetzic Soils deep plowing, ripping and liming feasibility studies, Flagstaff and Paintearth Counties, Alberta Agriculture. (Yields are from strips on farm fields).

[b] Number of reporting trials.

[c] Agricultural Reporting Area 4A data, Alberta Agriculture. (Farmers reported yields).

[d] Paintearth Mine Torlea Soil Reclamation Trials. Reference yields (reseeded natural Torlea soil).

Most plots were constructed by the fall of 1980; however, excessive wetness of the sodic spoil delayed completion of the Torlea Soil Experiment Plots until January 1981, when the spoil was frozen (Techman Engineering Ltd. 1982).

Topsoil and subsoil materials used in the construction of the Subsoil Depth, Bottom Ash and Slope Drainage experiments were removed from an area of Orthic Dark Brown Chernozemic and Dark Brown Solodic soils. An area of Dark Brown Solonetzic soils was selected for excavation of topsoil and subsoil materials used in the Torlea Soil Experiment. All soils were developed on clay loam textured till (Techman Engineering Ltd. 1979). Selected properties of materials determined from grab samples collected during construction for each experiment are given in Table 6 and soil quality is rated according to recent guidelines (Alberta Agriculture 1987).

One of the major aspects of reclamation of surface mined lands involves the use of readily available materials for soil reconstruction. Materials assessed for reclamation in this research include:

1. topsoil;
2. subsoil excavated prior to mining;
3. sodic mine spoil; and
4. bottom ash accumulated from the coal burning process.

Materials used in construction and referred to throughout this report are defined below:

1. Topsoil is loam to clay loam textured A horizon material removed from the native soils before mining. The original soil is rated as "Fair" topsoil for reclamation based on Alberta soil quality criteria (Alberta Agriculture 1987). Salinity is the main limitation. Originally electrical conductivity (EC) values were between 2 to 4 mS/cm. Topsoil used in the Torlea Soil Experiment had an "Unsuitable " rating because of its excessive sodicity (high sodium adsorption ratio, SAR).

Table 6. Selected properties of materials from grab samples taken during construction.

			pH		EC (mS/cm)		SAR		
Experiment	Material	n	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Suitability Rating[a]
Subsoil Depth	Topsoil	36	6.8	0.18	3.6	0.48	3.5	0.77	F(EC)
	Subsoil	60	7.8	0.10	5.8	0.67	8.4	1.60	P(EC:SAR)
	Spoil	24	8.0	0.14	2.9	1.00	23.9	2.73	U(SAR)
Torlea Soil	Topsoil	90	7.7	0.10	2.4	1.00	13.5	1.25	U(SAR)
	Subsoil	252	7.4	0.28	5.7	1.33	14.2	1.65	U(SAR)
	Spoil	21	7.7	0.21	2.7	0.72	20.2	4.64	U(SAR)
	Ash		7.8	0.23	1.2	0.23	24.5	3.71	--
Bottom Ash	Topsoil	30	6.8	0.19	3.4	0.72	4.5	2.42	F(EC:SAR)
	Subsoil	30	7.6	0.12	5.5	0.86	8.5	2.86	P(EC:SAR)
	Spoil	30	7.7	0.25	2.7	0.63	22.7	3.60	U(SAR)
Slope Drainage	Topsoil	48	6.8	0.39	3.5	1.49	5.9	4.16	F(EC:SAR)
	Subsoil	96	7.4	0.33	5.8	1.45	12.6	6.61	P(EC:SAR)
	Spoil	8	7.9	0.18	2.8	0.30	24.0	1.67	U(SAR)

Source: Techman Engineering Ltd. 1982, n = number of samples per reported mean.

[a] Alberta Soil Quality Criteria (Alberta Agriculture, 1987).

Ratings	Constraints
F - Fair	EC - High electrical conductivity (salinity)
P - Poor	SAR - High sodium adsorption ratio (sodicity)
U - Unsuitable	

2. Subsoil includes the B and C horizons plus underlying material that has chemical and physical properties suitable for sustaining vegetative growth. The subsoil used was a clay loam textured till which is "Fair to Poor" according to the Alberta soil quality criteria. High sodicity and salinity are the major limitations. Subsoil materials, consisting of shallow till and weathered bedrock of the Torlea Soil Experiment are rated "Unsuitable" because of high sodicity.
3. Spoil consists of sodic bedrock materials of the Horseshoe Canyon Formation. It is "Unsuitable" reclamation material because it has SAR values above 20. The relatively low EC values in comparison with the SAR values is characteristic of spoil materials of the Northern Great Plains (Power et al. 1978a).
4. Bottom ash is the waste product of coal burnt at the Battle River Thermal Power Station. It is a sandy textured, pumice-like material characterized by relatively high calcium content and potentially phyto-toxic concentrations of boron (McCoy et al. 1981).
5. Gypsum was applied at 20 tonnes per hectare (t/ha) as a surface amendment in the Torlea Soil Experiment. Also it was applied below the subsoil of three treatments of the Bottom Ash Experiment and one treatment of the Torlea Soil Experiment.

1.5 SOIL AND CROP HUSBANDRY

The soil reconstruction treatments were evaluated in terms of two cropping systems: cereal rotation and forage production. Agronomic activities conducted yearly are summarized below and details regarding seeding and fertilizer applications are given in Tables 7 and 8.

Table 7. Cereal plot seeding and fertilization practices.

Year	Seed Variety	Date of Seeding	Seed Rate	N P K Broadcast	N P K Placed
			------------	kg/ha	------------
1982	Neepawa Wheat	May 22	100	--	21-22-0
1983	Neepawa Wheat	Apr 30	100	35-36-0	--
1984	Bonanza Barley	May 2	67	45-46-22	23-23-0
1985	Neepawa Wheat	May 11	112	45-45-22	22-22-0
1986	Neepawa Wheat	May 10	134	27-28-26	23-24-0

Table 8. Forage plot cropping and fertilization practices.

	Cropping Practices			Fertilizer
Experiment	Variety	Seeding Method	Seeding Rate kg/ha	N-P-K Rate kg/ha
Subsoil Depth Torlea Soil Bottom Ash	Neepawa wheat (nurse crop)	press drill at 3-4 cm depth, May 2, 1982	55	1982:23-24-0
				1983:35-36-0
	Charlton			1984:45-46-22
	Bromegrass &	press drill	8	
	Rambler Alfalfa	broadcast	15	1985:45-45-22
Slope Drainage	Charlton Bromegrass &	broadcast	4	1986:22-104-22
	Beaver Alfalfa	broadcast	16	

1. Cereal Plots

Early May - cultivated twice and harrowed.
- NPK broadcast prior to seeding.
- NP placed with seed.

Late May to Early June - plots sprayed to control wild oats and broadleaf weeds.

August - plots harvested at maturity, yields measured.

September - plots fall cultivated.

2. Forage Plots

Early May - NPK broadcast.

July - forage harvested, dry yields determined.
- harvest dates: 1983, July 12; 1984, July 27; 1985, July 25; and 1986, July 31.

September - plot margins and compound trimmed to avoid snow trapping effects.

1.6 RESEARCH MONITORING

Several soil, crop and monitoring activities were conducted as part of the research program. Standardized procedures were used throughout and are outlined below.

1. Soil Fertility: Soil samples were taken each spring from forage and cereal plots to determine fertilizer requirements. Norwest Labs conducted the analyses and provided recommendations. The recommendations were followed to ensure that fertilizer applications met minimum crop requirements for average yields.
2. Yield Measurements: Forage yields were determined on a dry weight basis (kg/ha) calculated from entire plot fresh weights measured in the field and subsamples dried to constant weight. Grain yields in kg/ha were calculated from plot moist grain yields and subsamples oven dried for 24 hours at 60° C.

3. Soil Moisture Monitoring: Neutron probe access tubes were installed in all plots in 1982. A Campbell Scientific Subsoil Moisture Gauge, Model #503 was used for monitoring soil moisture. Measurements were taken using the same instrument, May through September, each year since 1983. In 1982 measurements commenced in July.
4. Soil Bulk Density Measurements: A Campbell Scientific Model #501 moisture and density probe was used to measure soil bulk densities in all access tubes at various depths within the reconstructed materials. Measurements were conducted with the same instrument in May 1983, the first records of soil bulk density following construction of these plots, September 1985, and June 1986. Monitoring was planned for autumn 1984 but the very early arrival of winter made it impossible to obtain measurements.
5. Soil Salinity: The soils in each plot were sampled each autumn at 15 cm intervals continuing into the underlying spoil. Chemical analyses included pH (in H_2O), EC (electrical conductivity, saturated paste), SAR (sodium adsorption ratio), saturation percent, soluble cations (Ca, Mg, Na, K) and soluble anions (SO_4, Cl), using standard analytical procedures (McKeague 1978).
6. Rainfall: A rainfall gauge was installed on the compound in 1983 and was monitored throughout each growing season by the Alberta Research Council.
7. Groundwater Levels: Three groundwater observation sites were established within the compound in 1985, and these have since been monitored monthly during the growing season.

8. Rooting Depth: Roots were described by noting depth of root penetration, as well as root abundance, size and orientation using standard definitions (Working Group on Soil Survey Data 1975). The standard unit is 2.5 cm square for fine, very fine and micro roots, and 1 m square for medium and coarse roots. To expedite root descriptions during sampling, these classes were converted to the number of roots in a core cross-section as follows:

	Number Per Unit Area Surface	Number Per Core Cross-section
ABUNDANCE		
- Very few	< 1	< 5
- Few	1 to 3	5 to 16
- Plentiful	4 to 14	> 16
- Abundant	> 14	also > 16
SIZE (mm)		
- Micro	< 0.075	very fine and fine recognized, medium and coarse cannot be accurately assessed in a core
- Very fine	0.075 to 1	
- Fine	1 to 2	
- Medium	2 to 5	
- Coarse	> 5	
ORIENTATION		
- Vertical	Oblique	
- Horizontal	Random	

1.7 STATISTICAL ANALYSIS

The treatments on the three replicates of each experiment are assessed in relation to forage and cereal (where applicable) production, saturation percentage, salinity, sodicity and sodium levels. Four main soil layers are considered in the statistical analysis: topsoil (15 cm surface layer), upper subsoil (15 to 20 cm layer below topsoil), lower subsoil (15 to 20 cm layer above spoil contact), and upper spoil (15 to 20 cm layer below upper limit of spoil).

As an introduction to the statistics used in the four experiments, the statistical procedures are briefly explained. Analysis of variance (ANOVA) is used to examine the variation in a data set, and to determine whether variation between treatments is greater than variation within treatments. The ANOVA tables for the Subsoil Depth Experiment crop and soil chemical analyses are given in Table 9. ANOVA tables for other experiments are presented later. F-tests of the significance of the treatments are constructed by comparing the variation attributable to treatments with the variation attributed to unknown or random factors (error). For example, a logical question to ask in these experiments might be, "does deeper subsoil always result in higher yields?". This question implies the possibility of increasing yields by x units for each unit of subsoil depth increase, which is a linear increase, and can be tested by a planned linear contrast. One could also ask, "is this increase in yield larger for the first added units of subsoil than for additional units?". Such a question could be tested by a planned quadratic contrast, which identifies the strength of curvature in the relationship between yield and depth of subsoil.

A researcher may be interested in testing whether two means are different even though no contrasts had been planned in advance for the comparison. In this situation one must be careful not to declare a difference significant that only appears so due to random chance. The chance of a random error of this nature increases as the number of means being compared increases. The Tukey's HSD (Honestly Significant Difference) test increases the "toughness" of the test as the number of means being compared increases in such a manner as to keep the error rate of the experiment at 5%. This results in an error rate for the specific comparison being made becoming smaller (often <1%) with increasing number of means. In short, it is a less powerful test than a planned comparison, that is, it is less likely to detect a difference that actually exists.

Error terms were pooled within main or subplots if they were not significantly different at $p = 0.05$. Pooling occurred hierarchically from highest order interactions to lowest. Pooling of main and subplot errors did not occur, and sample error was never pooled with experimental error.

Table 9. ANOVA tables for crop and soil analyses, Subsoil Depth Experiment.

CEREAL ANALYSIS (Forage has 1 yr less)

Source of Variation	Degrees of Freedom	
Replicate (R)	(R - 1) = 2	
Treatment (subsoil depth) (T)	(T - 1) = 5	
Linear Contrast		(1)
Quadratic Contrast		(1)
Error	(R - 1)(T - 1) = 10	
Year (Y)	(Y - 1) = 4	
Linear Contrast		(1)
Quadratic Contrast		(1)
Year x Treatment	(Y - 1)(T - 1) = 20	
Error	(T - 1)(R - 1)(Y - 1) = 40	

SOIL SALINITY ANALYSIS

Factor	Degrees of Freedom		Appropriate Error
Whole Plot			
Treatment (T)	5		TR
Linear Contrast		(1)	
Quadratic Contrast		(1)	
Crop (C)	1		CR
TC	5		TCR
TR	10[a]		
CR	2[a]		
TCR	10[a]		
Split Plot			
Year (Y)	4		YR
Linear Contrast		(1)	
Quadratic Contrast		(1)	
TY	20		TYR
YC	4		YCR
TYC	20		TYCR
YR	8[a]		
TYR	40[a]		
CYR	8[a]		
TYCR	40[a]		
Replicate (R)	2		S (TYCR)
S (TYCR)	180		

[a] Error

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[a] Note that this example assumes 6 treatments. For some of the dependent measures e.g. (SS1-SS2) there are less than 6 treatments. Degrees of freedom will adjust accordingly.

2. RESULTS

This section provides monitoring results of crop yields, soil chemistry, soil moisture, bulk density, and rooting depth collected from 1982 to 1986, in this order: Subsoil Depth, Torlea Soil, Bottom Ash and Slope Drainage. All statistically significant findings are noted in this Section as are any data limitations or special concerns. The technically meaningful findings are discussed in Section 3.

2.1 SUBSOIL DEPTH EXPERIMENT

2.1.1 Objectives

The objective of this experiment is to determine optimum depth of replacement subsoil over sodic mine spoil required to sustain agricultural capability. Plot layout is shown in Figure 2. A 15 cm cover of topsoil (A horizon) overlays increasing thicknesses of subsoil which are as follows:

Treatment	Subsoil Thickness
1	0 cm
2	25 cm
3	65 cm
4	135 cm
5	165 cm
6	335 cm

The null hypotheses pertaining to this experiment are as follows:

1. Crop productivity on reclaimed sodic spoil is not a function of subsoil depth (subsoil is defined as non-sodic material placed between spoil and replaced topsoil). If rejected identify optimal subsoil depth.
2. Forage and grain crops will not respond differently to varying subsoil depths. If rejected identify optimal subsoil depth for each crop.
3. Salts will not migrate from sodic spoil into subsoil. If rejected quantify the effect.
4. The subsoil/sodic spoil interface will not interfere with the vertical movement of water. If rejected quantify the effect.

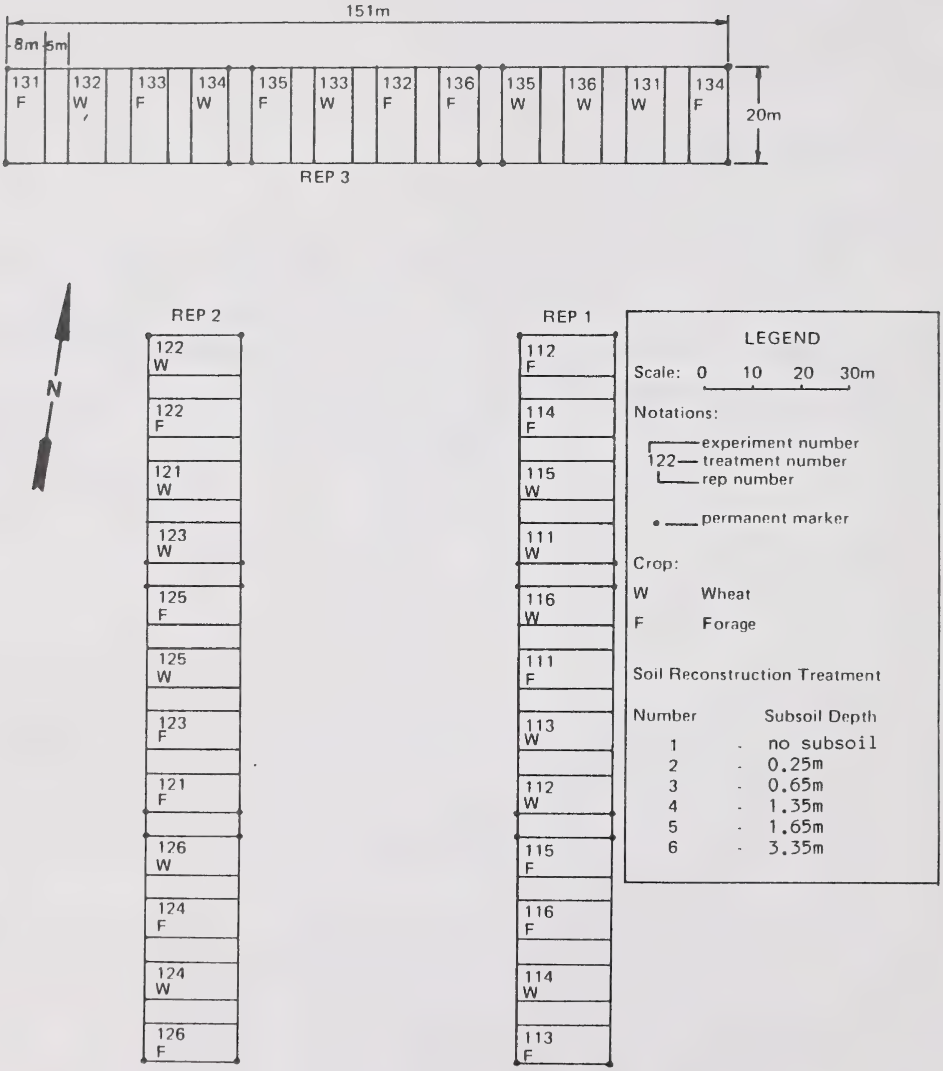


Figure 2. Plot layout, Subsoil Depth Experiment.

2.1.2 Subsoil Depth Statistical Analysis

This experiment was analyzed as a split-plot in time design with treatment and crop as main plot factors and year as the sub-plot factor.

Treatment main effects were decomposed into linear and quadratic planned comparisons (using coefficients as calculated from Myers 1979).

Post hoc tests were conducted using Tukey's HSD at p=0.05.

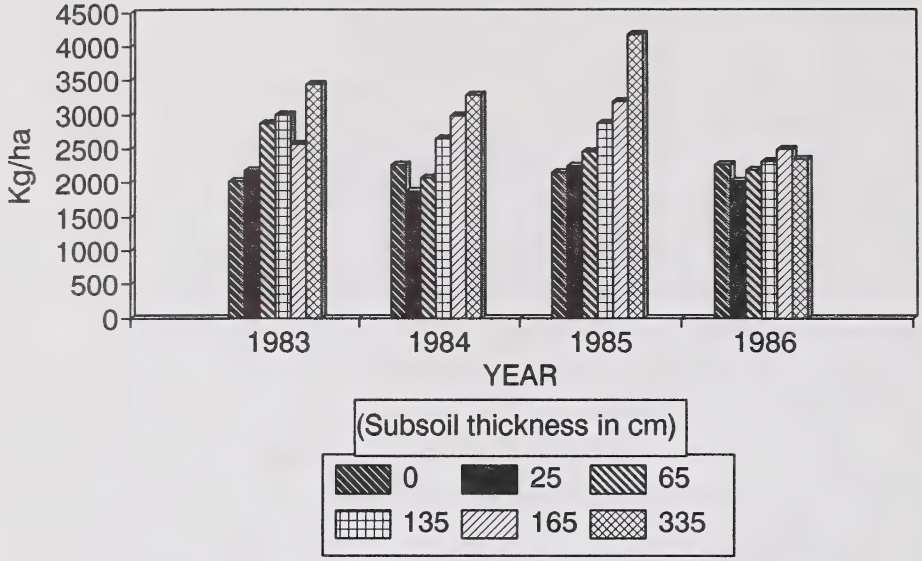
Year main effects were decomposed into planned linear and quadratic contrasts using coefficients from standard tables (Snedecor and Cochran 1980). Analyses were conducted on forage and cereal yields separately.

Soils were sampled at two randomly located points (never repeated) per plot. Yields were measured on a 4 m x 10 m central portion of each plot.

The analyses for chemical data on spoil were conducted over the last three years, 1984 to 1986 only, due to missing data in the previous two years, a result of differences between planned and actual depths of subsoil over spoil.

2.1.3 Subsoil Depth Yields

Forage yields are based on first cuts made each July, 1983 to 1986. In most years dry weather resulted in poor re-growth so second cuts were not made. Statistically significant findings included a decline in yields over the four year period, with significant variation from year to year. Also the linear comparisons indicated that the increasing yields with increasing subsoils thicknesses are significant (Figures 3 and 4; and Table 10) however, differences between individual treatments were not significant. Yields were lowest in 1986, which was attributable to severe drought that spring. Low forage yields in the final year likely make the decline over time significant. The increasing yields matching greater subsoil depths is a major practical finding of this experiment. The linear comparison is a powerful statistical test and confirms good yield responses to increasing subsoil thicknesses. But the lack of treatment difference makes it difficult to choose a minimum subsoil thickness based on yield.



n = 3, s.e. = 261, c.v. = 1435.

Figure 3. Forage yields by subsoil depth and year, 1983 to 1986.

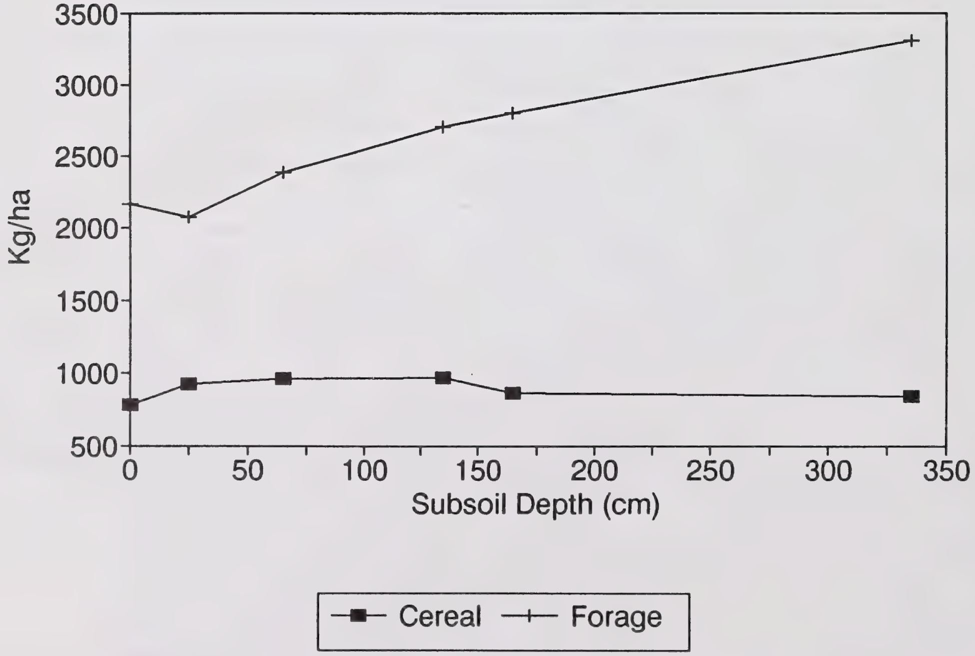


Figure 4. Average forage and cereal yields by subsoil depth.

Table 10. Forage and cereal yields, Subsoil Depth Experiment, 1982 to 1986.

Linear and quadratic comparisons are significant and so are deviations.

Year	1983	1984	1985	1986
Forage kg/ha	2676b[a]	2515ab	2840b	2263a

n = 18[b], s.e. = 103, c.v. = 387.

Significant factors:

Treatment	1	2	3	4	5	6
Cereal kg/ha	785a	928ab	963b	973b	869ab	844ab

n = 15, s.e. = 29.9, c.v. = 147.

Linear and quadratic contrasts are significant as are deviations.

Year	1982	1983	1984	1985	1986
Cereal kg/ha	1255c	409a	743b	1202c	859b

n = 18, s.e = 50, c.v. = 245.

Year x Treatment, Cereal kg/ha

	1982	1983	1984	1985	1986
1	1344	486	586	792	715
2	1445	431	626	1403	736
3	1247	385	952	1313	917
4	1366	364	865	1352	919
5	1070	378	743	1205	949
6	1061	410	687	1145	916

n = 3, s.e. = 74, c.v. = 360.

---

[a] means followed by the same letter are not significantly different at p=0.05).

[b] n = number of samples per mean
s.e. = standard error
c.v. = critical value

Barley was grown in 1984: in all other years wheat was grown. Grain yields in kg/ha are analyzed with no adjustment for different crops. Treatments 3 and 4, 65 and 135 cm subsoil, respectively, out-yielded all others, and were significantly higher than Treatment 1, topsoil over spoil. Yields across all treatments were moderate in 1982 and 1985, poor in 1984 and 1986, and very poor in 1983 (Table 10). The planned comparisons of yield versus subsoil thickness were not significant.

2.1.4 Subsoil Depth Soil Salinity Analysis

Results of soil chemical analyses are presented in a standardized format for all experiments as follows:

1. summary of statistically significant findings,
2. presentation of statistical data, and
3. identification of technically meaningful results.

In each instance, results for each key soil layer are given in order: topsoil (TS), upper subsoil (SS1), lower subsoil (SS2), spoil (SP), difference between lower and upper subsoil, and difference between spoil and lower subsoil. Saturation percentage, electrical conductivity, sodium concentration and sodium adsorption ratio are either tabulated or graphed. Note that only statistically significant findings ($p = 0.05$) are shown; hence, the variations in formats and kinds of data presented.

Table 11 highlights the statistical findings for the Subsoil Depth Experiment and clearly illustrates that major changes in all primary soil layers occurred in response to time (year). Crop and treatment effects were largely confined to the topsoil.

Tables 12 to 17 and Figures 5 and 6 present detailed results for primary soil layers and the principal parameters.

2.1.4.1 Topsoil. There have been several important changes in the five year period: saturation percentage, EC, Na and SAR levels all declined rapidly in the first two to three years and these declines have levelled off in the last

Table 11. Statistical summary for Subsoil Depth Experiment, salinity data, 1982 to 1986.

Layer Parameter	Tmt	Crop	Tmt x Crop	Yr	Yr x Tmt	Yr x Crop	Overall[a]
Topsoil							
Sat %				*			
EC		*		*		*	
Na		*		*	*		
SAR		*		*	*		
Upper Subsoil							
Sat %				*			
EC				*			
Na				*			
SAR				*			
Lower Subsoil							
Sat %	*			*	*		
EC				*			
Na				*			
SAR				*			
Spoil							
Sat %	*	*				*	
EC				*			
Na				*			
SAR				*			
Lower Subsoil - Upper Subsoil							
Sat %							*
EC							*
Na							*
SAR	*						
Spoil - Lower Subsoil							
Sat %							*
EC	*			*			*
Na				*			*
SAR	*						*

*significant at $p = 0.05$.

[a] Overall: average of all treatments from 1982 to 1986.

Table 12. Topsoil salinity, Subsoil Depth Experiment, 1982 to 1986.

Saturation %

Linear decline in time and significant quadratic contrast.

Year	1982	1983	1984	1985	1986
Mean Sat%	40c	35b	34ab	32a	34ab

n = 72, s.e. = 0.6, c.v. = 2.9.[a]

EC (mS/cm)

Crop - cereal (2.85)> forage (2.27).
Year - linear decline with time.
Crop x Year - forage declines more, and faster than cereal.

Year	1982	1983	1984	1985	1986	Mean
Cereal	3.2cd	3.4d	3.2cd	2.8bcd	1.7a	2.85
Forage	3.3d	2.6bc	2.4b	1.5a	1.5a	2.27
Mean	3.2	3.0	2.8	2.2	1.6	

n = 36, s.e. = 0.14 (except within year), c.v. = 0.63.

Na (me/L)

Crop - cereal (12.3 me/L) > forage (8.7 me/L).
Year - linear decline with time, see Figure 5.
Year x Treatment, see Figure 5.

SAR

Crop - cereal (3.1) > forage (2.4).
Year - linear decline with time, see Figure 6.
Treatment x Year, see Figure 6.

---

[a] s.e. = standard error

c.v. = critical value

Table 13. Upper subsoil salinity, Subsoil Depth Experiment, 1982 to 1986.

Saturation %

Linear decline in time and significant quadratic contrast.

Year	1982	1983	1984	1985	1986
Sat%	45c	42b	38a	38a	39a

n = 60, s.e. = 0.70, c.v. = 2.8.

EC (mS/cm)

Linear increase with time.

Year	1982	1983	1984	1985	1986
EC	5.3	5.4	6.2	6.1	5.9

n = 60, no significant differences between years.

Na (me/L)

The quadratic contrast is significant, peak in 1984.

Year	1982	1983	1984	1985	1986
Na	37	39	48	39	37

n = 60, no significant differences between years.

SAR

The quadratic contrast is significant, peak in 1984.

Year	1982	1983	1984	1985	1986
SAR	8.1a	8.0a	9.4b	8.2a	7.9a

n = 60, s.e. = 0.3, c.v. = 1.2.

Table 14. Lower subsoil salinity, Subsoil Depth Experiment, 1982 to 1986.

Saturation %

Treatment	1982	1983	1984	1985	1986	Mean
2	48ab	52abc	48ab	43a	44ab	47a
3	49abc	47ab	43a	42a	43a	45a
4	50abc	48ab	43a	43a	43a	45a
5	54abc	48ab	46ab	46ab	43a	47a
6	57abc	48ab	64c	46ab	59bc	55b
Mean	52c	48abc	49bc	44a	47ab	

n = 12, s.e. = 2.5, c.v. = 16.
Interactions
Year means n = 60, s.e. = 1.2, c.v. = 4.7.
Treatment means n = 60, s.e. = 1.55, c.v. = 6.6.

EC (mS/cm)

Linear increase with time is significant as is the quadratic contrast, peaking in 1985. There are also differences between years.

Year	1982	1983	1984	1985	1986
EC	6.7a	7.2ab	8.0b	8.5b	7.9b

n = 60, s.e. = 0.23, c.v. = 0.9.

Na (me/L)

The linear increase with time and quadratic contrast peaking in 1984 are significant.

Year	1982	1983	1984	1985	1986
Na	55	59	77	69	62

n = 60, no significant differences between years.

SAR

The linear increase with time and the quadratic contrast peaking in 1984 are significant. There are also differences between years.

Year	1982	1983	1984	1985	1986
SAR	12a	12a	15c	14bc	13ab

n = 60, s.e. = 0.4, c.v. = 1.6.

Table 15. Spoil salinity, Subsoil Depth Experiment, 1984 to 1986.

Saturation %

Treatment	1	2	3	4	5	6
Sat%	49a	132c	133c	126c	105b	102b

n = 72, s.e. = 4.12, c.v. = 17.3.

Crop - cereal (102) < forage (111).

Crop x Year	1982*	1983*	1984	1985	1986
Cereal	100	80	103ab	98a	104b
Forage	98	91	114c	110c	110c

*not included in ANOVA.
n = 36, s.e. = 0.8, c.v. = 5.8.

EC (mS/cm)

The linear increase and quadratic contrast over time are significant.

Year	1984	1985	1986
EC	6.3	7.7	7.5

n = 72, no significant difference between years.

Na (me/L)

The linear decrease and quadratic contrast over time are significant.

Year	1984	1985	1986
Na	71	75	69

n = 72, no significant difference between years.

SAR

The linear decrease and quadratic contrast showing a recent decrease are significant.

Year	1984	1985	1986
SAR	28	28	25

n = 72, no significant difference between years.

Table 16. Lower subsoil (SS2) minus upper subsoil (SS1) salinity, Subsoil Depth Experiment, 1982 to 1986.

Saturation %

Significant overall difference.

n = 300, SS2 (48) - SS1 (40) = 8.

EC (mS/cm)

Significant overall difference.

n = 300, SS2 (7.7) - SS1 (5.8) = 1.9.

Na (me/L)

Significant overall difference.

n = 300, SS2 (64) - SS1 (40) = 24.

SAR

Significant overall difference.

n = 300, SS2 (13.2) - SS1 (8.3) = 4.9.

Table 17. Spoil (Sp) minus lower subsoil (SS2) salinity, Subsoil Depth Experiment, 1984 to 1986.

Saturation %

Significant overall difference.

n = 180, Sp (106) - SS2 (48) = 58.

EC (mS/cm)

Significant overall difference.

n = 180, Sp (7.2) - SS2 (8.1) = -0.9

Significant linear decline in the magnitude of the difference.

Treatment	2	3	4	5	6
EC(Sp-SS2)	-1.4	-1.5	-1.4	-0.9	-0.1

n = 36.

The linear decline in the magnitude of the difference and the quadratic contrast are significant.

Year	1984	1985	1986
EC	-1.85	-0.75	-0.60

n=36.

Na (me/L)

Significant overall difference.

n = 180, Sp (72) - SS2 (69) = 3.

Linear and quadratic contrasts over time are significant.

Year	1984	1985	1986
Na(me/L)	-6.7	9.0	8.3

n = 36

SAR

Significant overall difference.

n = 180, Sp (27.2) - SS2 (14) = 13.2.

There is a significant linear decline with increasing thickness of subsoil.

Treatment	2	3	4	5	6
SAR	18	20	18	14	9

n = 36.

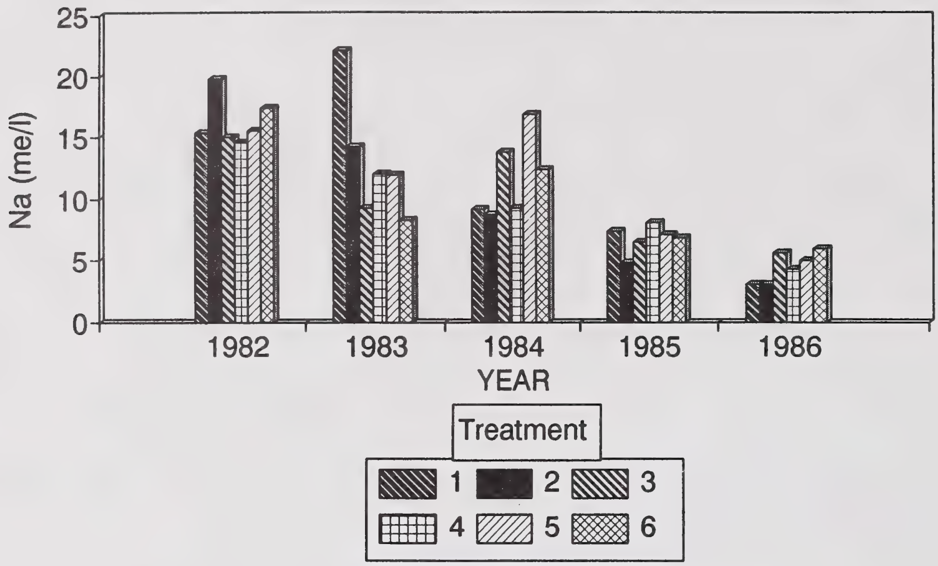


Figure 5. Topsoil Na levels by year and treatment.

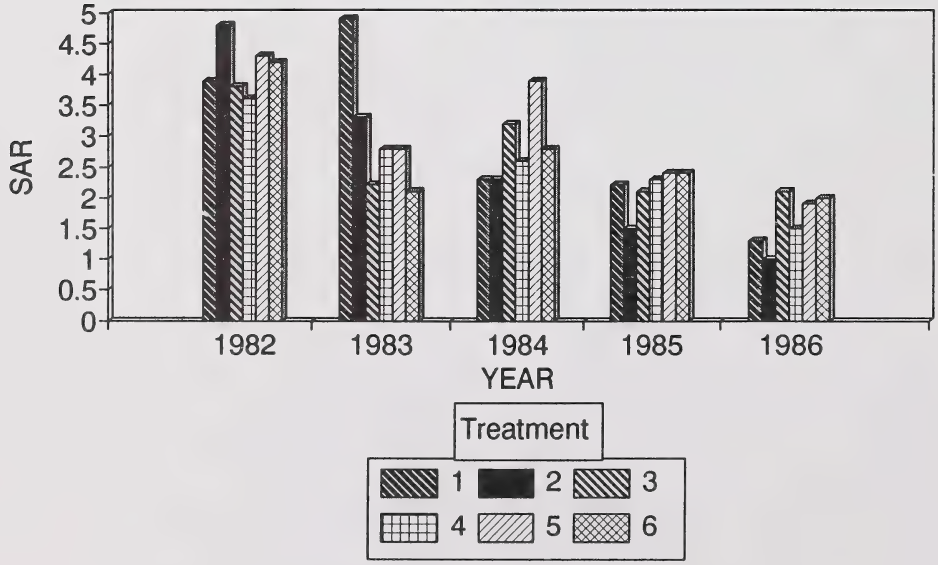


Figure 6. Topsoil SAR levels by year and treatment.

two years. Topsoil quality has improved from Fair (Alberta Agriculture 1987) to Good and this improvement was more pronounced and more rapid under forage than under cereal. Treatment differences evident in the early years disappeared with time.

2.1.4.2 Upper subsoil. This layer changed over time but responses to crops or treatments were not evident. Saturation percentage decreased the first two years. EC, Na and SAR levels all increased initially, peaked in 1984 then decreased to more or less original values. In terms of soil quality ratings for these parameters, the upper subsoils remained Poor throughout the five year period but if the recent improvements continue they could soon be upgraded to Fair.

2.1.4.3 Lower subsoil. Changes followed a similar pattern to that of upper subsoil, but there are important differences: final EC, Na and SAR values were slightly higher than initial values, and overall soil quality was inferior. Lower subsoils were initially Poor, became Unsuitable in 1984 and 1985, and then reverted to Poor in the final year.

2.1.4.4 Spoil. Characteristics changed such that saturation percentages differed among treatments being: highest in Treatments 2, 3, 4; intermediate in 5, 6; and lowest in 1. Cereal plots had lower values than forage plots. Due to changes in sampling depths only 1984 to 1986 could be analyzed consistently during which time EC increased and levelled off; Na increased then decreased to near original values; and SAR decreased slightly in the final year. While EC levels are within the Fair rating and saturation percentage is Poor, the excessive SAR makes spoils clearly Unsuitable.

2.1.4.5 Lower minus upper subsoils. The upper subsoils are generally one class better in quality because they have lower saturation percentage, EC, Na and SAR levels than lower subsoils.

2.1.4.6 Spoil minus lower subsoil. Comparisons show expected overall differences reflecting material characteristics. For example, spoil had higher saturation percentage, Na and SAR but lower EC than lower subsoil. In addition, there are important treatment and time effects. EC differences (spoil - lower subsoil) decreased with increasing depth to spoil and decreased from 1984 to 1986. Subsoil was initially more saline than spoil. Na concentration in spoil increased relative to that in lower subsoil. SAR differences decreased with increasing subsoil depth. Thus EC and SAR values in these layers indicate that as subsoil thickness increases, there is increasing similarity between layers above and below the interface. Analysis of 1984 to 1986 data indicates that the change may be levelling off thereby approaching a new equilibrium.

2.1.5 Soil Moisture

Soil moisture percentage was measured monthly through the growing season, by neutron probe. Major factors considered in gathering and interpreting moisture data included:

1. moisture availability to plants and depth of rooting;
2. occurrence of saturated conditions, or perched water table;
3. differences between crops; and,
4. effects of moisture and crops on soil development.

As an aid to interpreting moisture measurements, special studies on moisture availability were conducted in 1987 and results are summarized in Table 18.

It is known that in soils that permit good root development by wheat, moderate stress seldom occurs until 75 to 80% of the available moisture has been extracted from the major root zone (Hagan et al. 1967). Based on this information, a limit of 5% above wilting point was set for all materials as the lower limit of adequate (readily available) moisture for crops.

To summarize the data, soil moisture classes were developed indicating droughty (wilting point plus 5%) and readily available soil moisture levels for crop growth. The frequency of occurrence of months with readily available moisture content was then tabulated (Table 19).

Table 18. Soil moisture availability, Subsoil Depth Experiment.

	Bulk Density (g/cm^3)	Wilting Point (WP) (Wt.%)	Wilting Point (WP) (Vol.%)	Field Capacity (FC) (Wt.%)	Field Capacity (FC) (Vol.%)	FC - WP (Vol.%)
Topsoil[a]	1.3	9	12	18	24	12
Subsoil[b]	1.7	12	20	23	39	19
Spoil[c]			20		39	19

[a] Based on mean of 15 samples

[b] Based on mean of 30 samples

[c] Treated as equivalent to subsoil. These values underestimate the WP and FC of spoil materials which cannot be measured successfully with the moisture tension apparatus. Nevertheless, the values used allow detection of a water table.

% moisture (wt. basis) x bulk density (g/cm^3) = % moisture (vol. basis)

Table 19. Percentage of months with moisture content readily available to plants[a], May to September, Subsoil Depth Experiment, 1982 to 1986.

Treatment	Material[b]	Depth (cm)	Cereal	Forage
1	TS	0 to 15	55%	50%
	SP	15 to 30	60	60
	SP	125 to 140	100	100
2	TS	0 to 15	65	55
	SS	15 to 30	45	25
	SS[c]	40 to 55	80	50
	SP[c]	85 to 100	100	100
	SP	150 to 165	100	100
3	TS	0 to 15	55	55
	SS	15 to 30	50	45
	SS	40 to 55	85	45
	SS[c]	65 to 80	95	65
	SP	110 to 115	100	100
	SP	185 to 200	100	100
4	TS	0 to 15	60	50
	SS	15 to 30	45	25
	SS	40 to 55	80	35
	SS	65 to 80	85	25
	SS	85 to 100	95	25
	SS	100 to 115	85	55
	SS[c]	125 to 140	100	100
	SP	185 to 200	100	100
	SP	235 to 250	100	100
5	TS	0 to 15	70	55
	SS	15 to 30	55	25
	SS	40 to 55	85	40
	SS	65 to 80	95	35
	SS	85 to 100	95	30
	SS	100 to 115	100	30
	SS	125 to 140	100	35
	SS[c]	150 to 165	100	90
	SP[c]	185 to 200	100	100
	SP	235 to 250	100	100
	SP	300 to 315	100	100
6	TS	0 to 15	60	50
	SS	15 to 30	50	30
	SS	40 to 55	80	45
	SS	65 to 80	90	35
	SS	85 to 100	95	25
	SS	100 to 115	95	20
	SS	125 to 140	90	15
	SS	150 to 165	90	60
	SS	165 to 200	100	80
	SS	235 to 250	95	85
	SS	300 to 315	100	100
	SS[c]	335 to 350	100	100

[a] TS = greater than 14% moisture, SS and SP = greater than 17% (see Table 18).

[b] TS=Topsoil, SS=Subsoil, SP=Spoil [c] Possible composite of materials

Differences in moisture content between Subsoil Depth treatments and cereal and forage crops are clear from Table 19. On cereal plots the frequency of monthly moisture contents at adequate levels varies little between Subsoil Depth treatments. Variations are generally confined to the upper 30 cm on all treatments. This probably reflects shallow rooting depth of cereal crops or the inability of roots to penetrate deeper. Much of the moisture stored in the profile was not used by the crop despite the fact that it was well within the available range. Caution is advised in interpreting these frequencies in relation to crop growth, in that spring moisture reserves or fall rainfall did not necessarily contribute to crop growth.

By contrast, on forage plots, depths to high frequency of readily available moisture vary with the depth to spoil. Little to no readily available moisture was found at most months below topsoil to about 30 cm above the spoil interface. Lowermost subsoil and spoil remained moist in all treatments. Maximum moisture levels were also examined, but they seldom exceeded field capacity and never approached saturation percentage. This indicates that water tables were absent within the monitoring depths and periods.

Limitations of the data include calibration of the moisture readings; determination of wilting point and field capacity of disturbed samples and converting values to those in very dense materials; and inability to determine moisture limits in spoil; therefore, caution is advised in using the absolute moisture values. The wilting points appear to be accurate in that they match driest levels (powder dry soil) measured in topsoils and subsoils. Lowest moisture levels for spoils were 10% higher than shown, but spoils were at least slightly moist when observed. Regardless, roots did not penetrate spoil so moisture was unavailable to the crops. Comparisons of cereal versus forage and data within years are relative and should be accurate. Likewise, observed moisture contents were well below saturation percentage so there is little chance of failing to recognize a water table.

2.1.6 Bulk Density

Selected bulk density data obtained by density probe measurements taken in 1983, 1985 and 1986 are summarized in Table 20. Values shown were chosen to focus on the root zone and to avoid possible composite readings at the subsoil/spoil interface using the density probe. Caution is advised in interpreting readings in that probe versus gravimetric readings may differ for topsoils and subsoils as demonstrated by comparison of probe values versus gravimetric samples taken in 1987 (Leskiw et al. 1988). Nevertheless, it is clear that all subsoil bulk densities are very high and there is little difference among crops, treatments or depths. There appears to be a slight decrease in topsoil and upper subsoil densities over time based on probe measurements. This, however, is not supported by gravimetric samples taken in 1987.

Duplicate core samples taken in Replicate 2 in 1987, and probe readings from all replicates, indicated the following soil densities:

Layer	Mean Bulk Density Cores (g/cm^3)	Mean Bulk Density Probe Values (g/cm^3)
Topsoil (0 to 15 cm)	1.34	1.39
Subsoil (15 to 30 cm)	1.80	1.62
Subsoil (30 to 45 cm)	1.77	1.75
Number of samples/mean	24	48

The topsoil and subsoil densities at 30 to 45 cm are very similar to those measured using the density probe which implies that the probe measurements are reliable at depth. The larger difference in the upper subsoil may be attributable to a probe reading that is influenced by soil disturbance in the vicinity of the access tube extension.

2.1.7 Root Distribution

Observations of forage root distribution made during soil sampling indicated similar results in 1985 and 1986. Topsoil contained plentiful to abundant very fine and fine roots in all treatments. In Treatments 1 (no subsoil) and 2 (25 cm subsoil) there were few roots penetrating below the topsoil to about 15 cm into the spoil. In other treatments (65 cm or more subsoil) there were few roots to about 40 cm, very few roots to 120 cm and

Table 20. Selected bulk density values (g/cm^3), Subsoil Depth Experiment.

Material	1983 Cereal	1983 Forage	1985 Cereal	1985 Forage	1986 Cereal	1986 Forage	1987 Cereal	1987 Forage
1. Topsoil (all Trts) n = 36	1.65	1.72	1.46	1.55	1.23	1.37	1.39	1.40
2. Upper Subsoil (Trts 3 to 6) n = 24	1.84	1.84	1.75	1.70	1.70	1.70	1.61	1.63
3. Lower Subsoil (Trts 3 to 6) n = 24	1.83	1.78	1.79	1.75	1.82	1.78	1.81	1.74
4. Lower Spoil (Trts 1 to 5) n = 30	1.53	1.53	1.46	1.47	1.51	1.53	1.49	1.45

Notes: Densities determined by density probe and converted to dry weight basis by subtracting moisture content as measured by neutron moisture probe. Standard deviations for each year, treatment and crop (i.e. n = 6) were generally within the following ranges: topsoil 0.1 to 0.3; subsoil 0.03 to 0.20; spoil 0.02 to 0.26. Upper subsoils had slightly higher standard deviations than deeper subsoils. These generalizations apply to all experiments.

none below. Alfalfa taproots may have grown deeper but these were rarely intersected during soil coring. Within the subsoil, roots were often compressed in fractures between clods much as they are in the planar voids between columns in B horizons of undisturbed solonetzic soils. Occasionally, root mats were observed above the subsoil/spoil interface in Treatments 1, 2 and 3.

Cereal crop roots were found to have a similar distribution in Treatments 1 and 2, that is, plentiful to abundant fine and very fine roots in the topsoil and few roots below extending some 15 cm into the spoil. In remaining treatments with deeper subsoils there were few roots to 30 to 40 cm below ground surface, very few to about 60 cm and usually none below 60 cm. As with forages, cereal roots were often "exped" and compressed within the subsoil.

2.2 TORLEA SOIL EXPERIMENT

2.2.1 Objectives

This experiment assesses methods of reclaiming lands mined from areas of Torlea Soils (Solonetzic Order) which are only suitable for perennial forage crops. The objectives are to identify the preferred salvageable soil horizons or horizon blends within the Torlea soil profile for use in root zone reconstruction, and to assess various soil amendments as potential aids in crop production.

The treatments tested on three replicates are:

Treatment	Thickness of Layers
1	spoil
2	20 cm A/spoil
3	20 cm A/20 to 30 cm B+C/spoil
4	20 cm A/45 to 55 cm B+C/spoil
5	20 cm A/75 to 90 cm C/spoil
6	20 cm A/100 to 115 cm C/spoil
7	20 cm A/45 to 60 cm C/20 to 35 cm ash/spoil

The null hypotheses are:

1. Forage crop performance on reclaimed sodic spoil is not influenced by application of black solonetzic horizons in various thicknesses and combinations. If rejected, identify best thickness and combination of horizons.
2. Forage crop performance on various thicknesses and combinations of black solonetzic horizons is not influenced by surface application of gypsum or bottom ash. If rejected, quantify the effect.

Surface amendments of 15 cm bottom ash and 20 t/ha gypsum were each spread on each of two subplots and incorporated during cultivation. A control formed the third subplot of each treatment. The plot layout is shown in Figure 7. Soils were sampled at one location per subplot (i.e. amendment x treatment). Plot yields were measured on 2 m x 6 m central portions of each subplot.

2.2.2 Statistical Analysis

The Torlea Soil Experiment was analyzed as a split-split-plot design with treatments as the main plot factor, amendment as the subplot factor and year as the sub-subplot factor. The ANOVA table for analyzing yield and soils data for this experiment is given in Table 21.

The amendment main effect was analyzed as three planned contrasts. Year main effects were decomposed into planned linear and quadratic contrasts using standard coefficients (Snedecor and Cochran 1980). Additional post hoc comparisons, including comparisons of treatment means, were conducted using Tukey's HSD at $p=0.05$.

Due to considerable differences in sampling depths for upper spoil in all years the analysis for upper spoil was not conducted. Considerable variation in subsoil depths over spoil occurs such that in one replicate upper spoil may be at the same depth as lower spoil in another. Analysis could be done by disregarding depths and simply comparing materials below the interface but then it would be questionable whether results from markedly different depths are comparable.

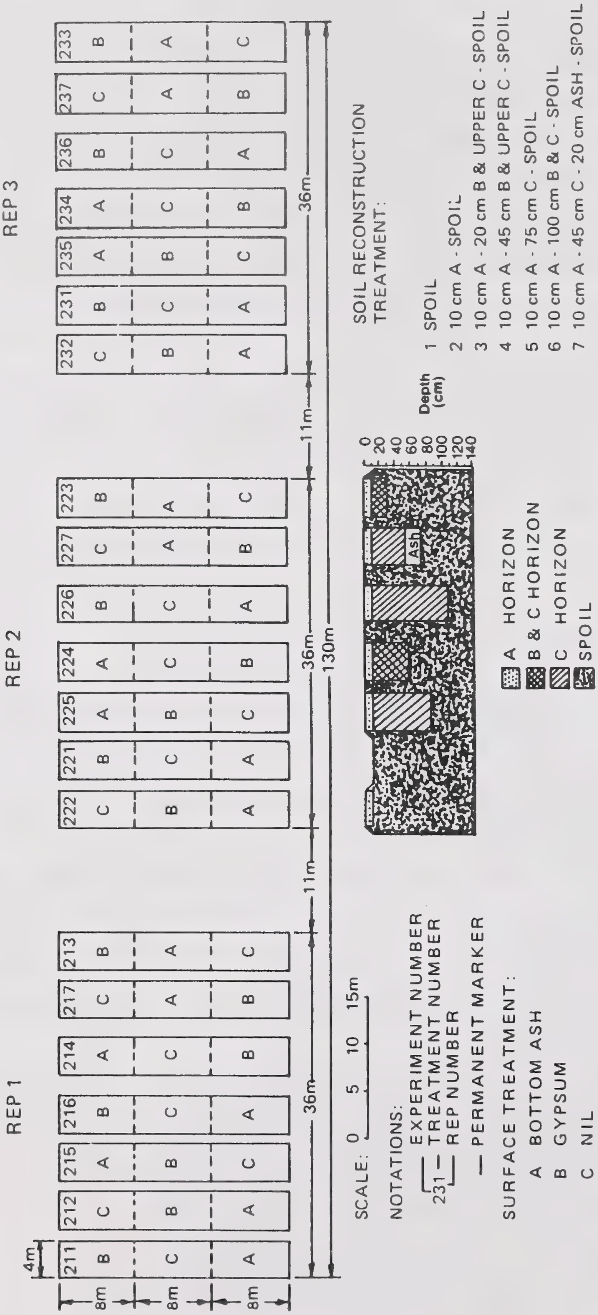


Figure 7. Plot layout, Torlea Soil Experiment.

Table 21. ANOVA table for crop and soil analyses, Torlea Soil Experiment.

Effects	Degrees of Freedom	Appropriate Error
Whole Plot		
Treatment (T)	5	TR
Replicate (R)	2	
TR	10[a]	
Split Plot		
Amendment (A)	2	AR
Bottom ash vs. gypsum contrast	(1)	
Bottom ash vs. control contrast	(1)	
Gypsum vs. control contrast	(1)	
AT	10	ATR
AR	4[a]	
ATR	20[a]	
Split-Split-Plot		
Year (Y)	4	YR
Linear contrast	(1)	
Quadratic contrast	(1)	
YT	20	YTR
YA	8	YAR
YTA	40	YTAR
YR	8[a]	
YTR	40[a]	
YAR	8[a]	
YTAR	80[a]	

[a] Error

---

[a] Note that this example assumes 6 treatments. For some of the dependent measures eg. (SS1-SS2) there are less than 6 treatments. Degrees of freedom will adjust accordingly.

2.2.3 Torlea Crop Yields

Forage yields were measured on first cuts taken each July, 1983 to 1986, and reported on a dry weight basis. Results are not presented for Treatment 1 which had little growth on ash amended plots and no growth on the others. Yields for Treatments 2 to 7 are given in Table 22: they were lowest for Treatment 2, highest for Treatments 3 to 6, and intermediate for Treatment 7. This pattern indicates increasing yields corresponding to increasing subsoil thickness from 20 to 115 cm; however, trend is not statistically significant. Treatment 7 with a buried ash layer between the spoil and subsoil produced inferior yields compared to subsoil alone, regardless of subsoil thickness.

Surface amendments had important effects on crop growth. The control plots yielded lowest, gypsum treated plots were intermediate and almost statistically higher than controls, and ash amended plots yielded highest.

Time also had a significant effect in that yields peaked in 1984 and declined subsequently. Time amendment interactions were important in that yields on ash > gypsum > control in all years except 1985. Poor yields on ash amended plots in 1985 are likely attributable to serious gopher damage confined to these plots.

2.2.4 Torlea Soil Salinity Analysis

Summary Table 23 indicates that there were important salinity differences in topsoils and to a lesser extent in upper subsoils in response to treatments, amendments, time and two-way interactions of these. Lower subsoils were much less responsive. This experiment is more complex than the others and analyses indicated a wider range of statistically significant findings.

2.2.4.1 Topsoil. Saturation percentage decreased over time, Figure 8, and it was affected by amendments such that control plots had higher values than ash and gypsum treated plots (Table 24, Figure 8). Nevertheless, all saturation percentages remained largely within the Fair quality rating throughout the monitoring period. Their largest impact is on interpretation

Table 22. Torlea Soil Experiment, crop yields 1983 to 1986.

Treatment	2	3	4	5	6	7
kg/ha	1872a	3514b	3700b	3761b	3813b	3168ab

n = 36, s.e. = 325, c.v. = 1595.

Amendment	1 (Ash)	2 (Gypsum)	3 (Control)
kg/ha	3624b	3292a	2986a

n = 72, s.e. = 113, c.v. = 330.

Year - linear and quadratic contrasts indicate a decline with time and a peak in 1984, and there are differences between years.

Year	1983	1984	1985	1986
kg/ha	3397b	3998c	3033ab	2783a

n = 54, s.e. = 138, c.v. = 520.

Year x Amendment

Year	1983	1984	1985	1986
Ash	4319c	4174c	2749ab	3256abc
Gypsum	3186abc	3942c	3355abc	2685a
Control	2642a	3878bc	2994abc	2408a

n = 18, s.e. = 240, c.v. = 1166 (not within given year).

Table 23. Statistical summary for Torlea Soil Experiment, salinity data, 1982 to 1986.

Layer Parameter	Tmt	Amend	Tmt x Amend	Yr	Yr x Tmt	Yr x Amend	Overall
Topsoil							
Sat %	*	*	*	*	*	*	
EC	*	*	*	*	*	*	
Na	*	*	*	*	*	*	
SAR	*	*	*	*	*	*	
Upper Subsoil							
Sat %	*			*	*	*	
EC		*		*	*		
Na		*		*	*	*	
SAR				*			
Lower Subsoil							
Sat %				*			
EC				*			
Na				*			
SAR				*			
Lower Subsoil - Upper Subsoil							
Sat %	*				*		
EC		*					*
Na		*					*
SAR	*						*

Significant at p = 0.05.

Table 24. Topsoil salinity, Torlea Soil Experiment, 1982 to 1986.

Saturation %

Treatment	2	3	4	5	6	7
Sat%	81b	61a	62a	62a	70ab	65a

n = 45, s.e. = 2.92, c.v. 14.3.

Amendment - ash (63) and gypsum (65) < control (72).
Year - linear and quadratic contrasts are significant, and there are differences between years.

Year	1982	1983	1984	1985	1986
Sat %	87c	69b	62a	58a	57a

n = 54, s.e. = 1.6, c.v. = 6.2.

Treatment x Amendment

Treatment	2	3	4	5	6	7
Ash	77cd	57ab	56a	59ab	69abc	60abc
Gypsum	75bcd	60abc	63abc	60abc	68abc	64abc
Control	91d	65abc	67abc	68abc	72abc	70abc

n = 15, s.e. = 3.2, c.v. = 17.6.

Treatment x Year, see Figure 9.
Year x Amendment, see Figure 8.

EC (mS/cm)

Treatment	2	3	4	5	6	7
EC	4.1b	2.2a	2.2a	2.5a	3.3ab	2.6a

n = 45, s.e. = 0.23, c.v. = 1.2.

Amendment	Ash	Gypsum	Control
EC	1.7a	4.1c	2.7b

n = 90, s.e. = 0.12, c.v. = 0.4.

Year - the linear decrease with time is significant.

Year	1982	1983	1984	1985	1986
EC	3.4	3.5	3.0	2.3	2.0

n = 54. No difference between years.

Treatment x Amendment

Treatment	2	3	4	5	6	7
Ash	2.5ab	1.4ab	1.3ab	1.8ab	2.0ab	1.1a
Gypsum	6.2d	3.3ab	3.4ab	2.8ab	5.2cd	3.8bc
Control	3.6b	1.9a	1.9a	2.9b	2.8b	2.8b

n = 15, s.e. = 0.28, c.v. = 1.5.

Year x Treatment, see Figure 10.

(Continued...)

Table 24. Topsoil salinity, Torlea Soil Experiment, 1982 to 1986 (Concluded).

Na (me/L)

Treatment	2	3	4	5	6	7
Na	40c	15a	17ab	19ab	27b	21ab

n = 45, s.e. = 2.3, c.v. = 11.3.

Amendment	Ash	Gypsum	Control
Na	15a	29b	26b

n = 90, s.e. = 1.3, c.v. = 4.6.

Year - The linear decline and quadratic contrasts are significant

Year	1982	1983	1984	1985	1986
Na	27	31	30	17	11

n = 54.

Treatment x Amendment

Treatment	2	3	4	5	6	7
Ash	28cd	10ab	11abc	17abc	18abc	8a
Gypsum	53e	18abc	22abcd	13abc	37de	28cd
Control	39de	16abc	19abc	26bcd	26bcd	27bcd

n = 15, s.e. = 3.2, c.v. = 17.6.

Year x Treatment, see Figure 11.
Year x Amendment, see Figure 13.

SAR

Treatment	2	3	4	5	6	7
SAR	18b	6.2a	8.7a	8.4a	10a	9.3a

n = 45, s.e. = 0.94, c.v. = 4.6.

Amendment	Ash	Gypsum	Control
SAR	9.5b	7.8a	13c

n = 90, s.e. = 0.40, c.v. = 1.4.

Year - The linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
SAR	13	11	13	8.9	4.4

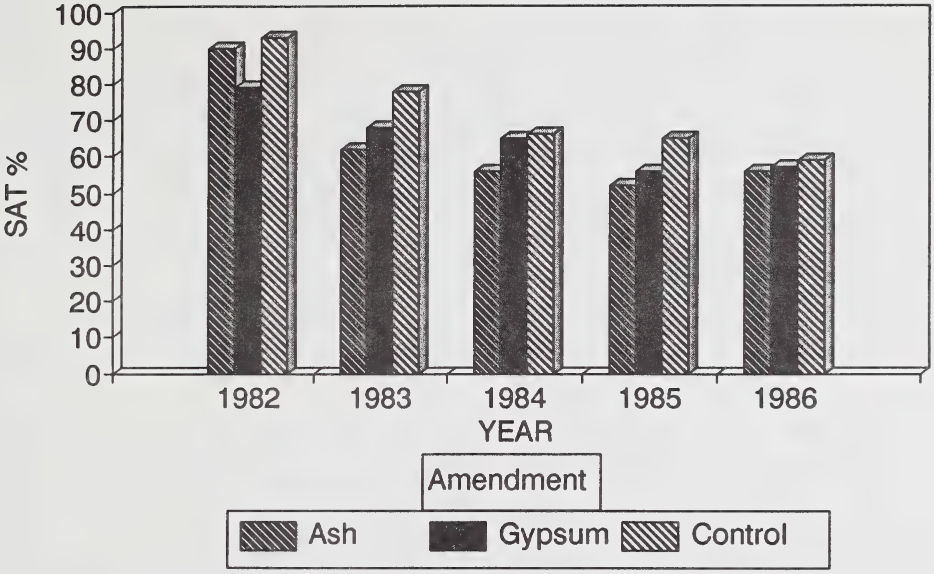
n = 54.

Treatment x Amendment

Treatment	2	3	4	5	6	7
Ash	19fg	5.5ab	6.7abcd	11bcde	9.7bcde	5.9abc
Gypsum	14ef	5.2a	7.0abcd	3.8a	8.5abcd	8.2abcd
Control	22g	7.9abcd	12de	11bcde	12de	14ef

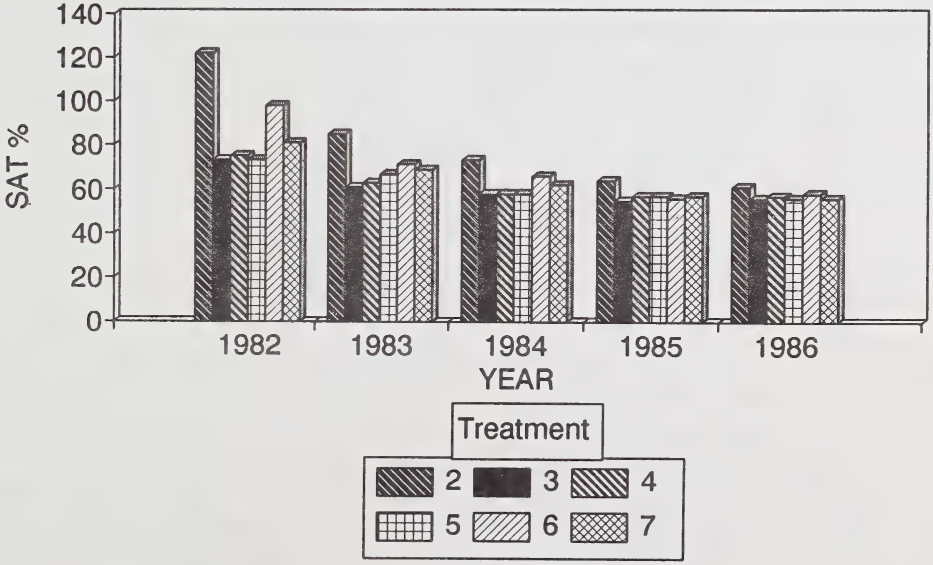
n = 15, s.e. = 0.97, c.v. = 5.4.

Treatment x Year, see Figure 12.
Amendment x Year, see Figure 14.



n = 18, s.e. = 2.8, c.v. = 13.4.

Figure 8. Topsoil saturation percentage by year and amendment, Torlea Soil Experiment, 1982 to 1986.



n = 9, s.e. = 3.9, c.v. = 21.

Figure 9. Topsoil saturation percentage by year and treatment, Torlea Soil Experiment, 1982 to 1986.

of changes in soil chemistry and this is discussed in Section 3. EC, Na and SAR values all declined over time with a slight peak in 1983 and 1984 and all showed similar patterns among treatments. Treatment 2 (topsoil over spoil) had higher values than Treatments 3 to 7 (Figure 9), with Treatment 6 being highest among the latter. Amendments had predictable effects: EC was lowest on ash plots and highest on gypsum treatments; Na was lowest on ash and similar on gypsum and control plots; and SAR was lowest on gypsum plots and highest on control plots.

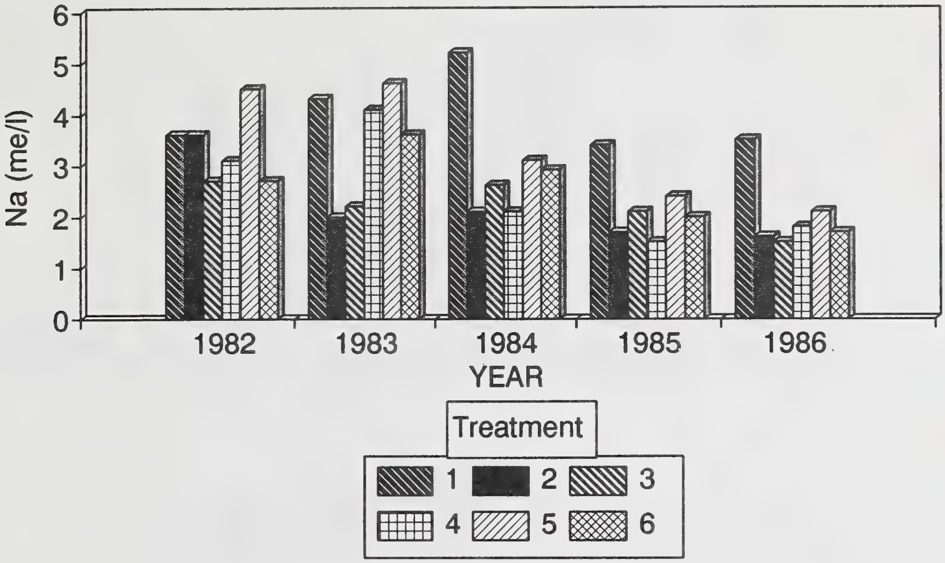
Interactions revealed several very important results:

1. Treatments 2 and 6 had higher EC and Na levels on gypsum versus control and ash plots,
2. Treatment 2, topsoil over spoil, improved (EC, Na, SAR values declined) slower and less than Treatments 3 to 7 with topsoil over subsoil (Figures 10, 11, 12),
3. Na levels were considerably lower on ash than gypsum and control plots in 1983 and 1984 than in other years (Figure 13),
4. SAR levels were markedly lower in 1982 on gypsum treatments whereas they decreased to comparable values on ash plots in 1983. Differences between controls versus ash and gypsum plots were disappearing in the latter years (Figure 14).

Topsoil quality improved considerably over time. Treatments 3 to 7 with subsoil over spoil all had topsoil salinities that improved from Fair or Poor in the first couple years to Good in 1986, while Treatment 2 topsoils remained Fair in 1986. SAR values improved from Poor or Unsuitable to Good for Treatments 3 to 7 and remained Poor for Treatment 2.

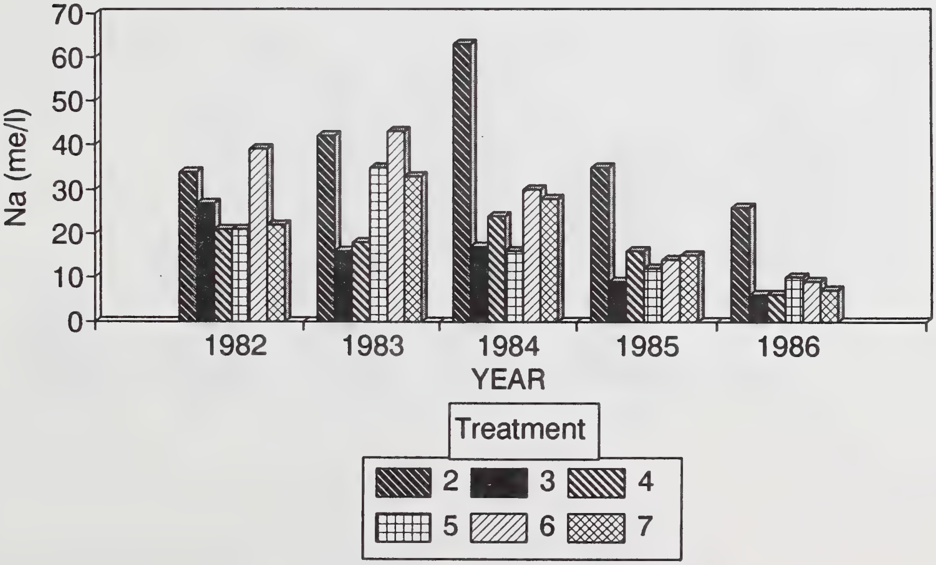
2.2.4.2 Upper subsoils. This layer changed over the five year period, in general, degrading the first three years then improving (Table 25). Saturation percentage decreased during 1982 to 1984 then levelled off (Figure 15). EC levels increased the first two years then remained between 7 and 8 mS/cm. Na and SAR levels also increased until 1984 but then decreased.

The effects of surface amendments were also reflected in upper subsoils. Gypsum and ash amended plots had highest and lowest EC and Na levels, respectively. SAR was not significantly affected.



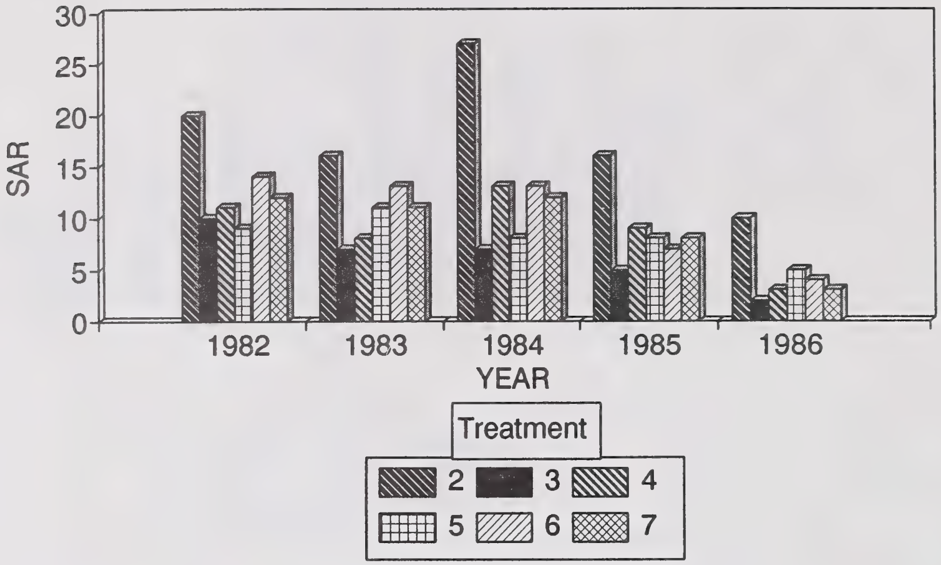
n = 9, s.e. = 0.35, c.v. = 1.9.

Figure 10. Topsoil EC by year and treatment, Torlea Soil Experiment, 1982 to 1986.



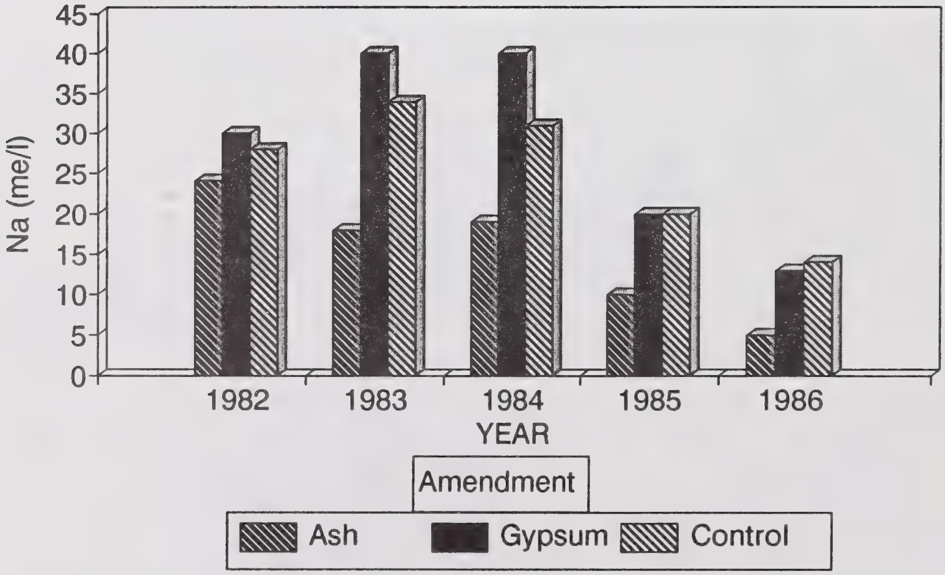
n = 9, s.e. = 3.39, c.v. = 18.6.

Figure 11. Topsoil Na by year and treatment, Torlea Soil Experiment, 1982 to 1986.



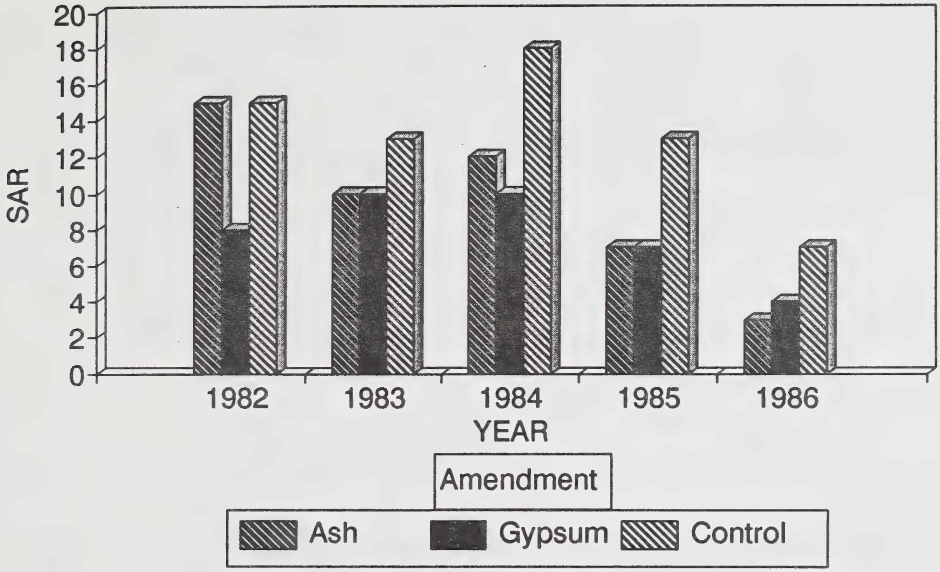
n = 9, s.e. = 1.2, c.v. = 6.6.

Figure 12. Topsoil SAR by year and treatment, Torlea Soil Experiment, 1982 to 1986.



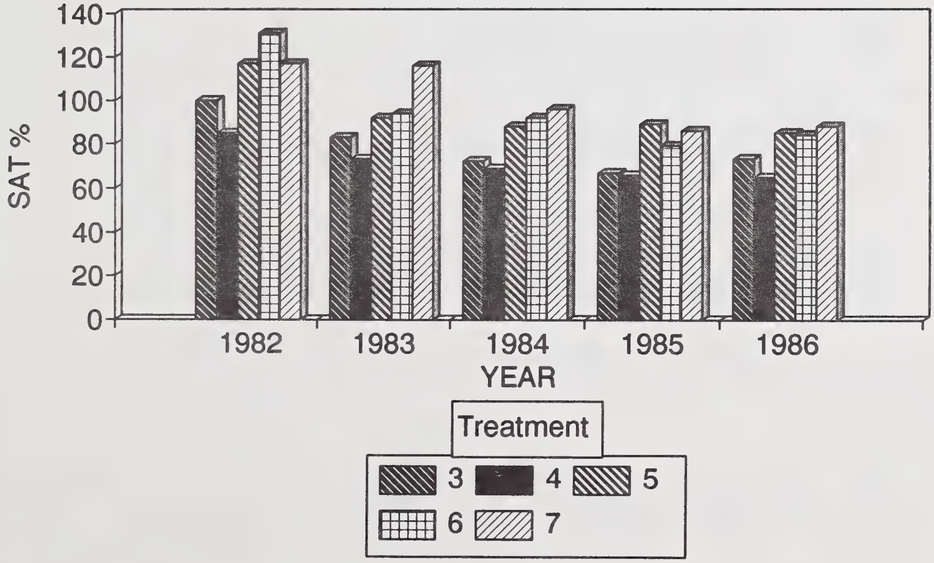
n = 18, s.e. = 2.39, c.v. = 11.5.

Figure 13. Topsoil Na by year and amendment, Torlea Soil Experiment, 1982 to 1986.



n = 18, s.e. = 0.72 c.v. = 3.5.

Figure 14. Topsoil SAR by year and amendment, Torlea Soil Experiment, 1982 to 1986.



n = 9, s.e. = 4.0, c.v. = 21.

Figure 15. Upper subsoil saturation percentage by year and treatment, Torlea Soil Experiment, 1982 to 1986.

Table 25. Upper subsoil salinity, Torlea Soil Experiment, 1982 to 1986.

Saturation %

Treatment	3	4	5	6	7
Sat %	70a	72ab	94bc	96c	101c

n = 45, s.e. = 4.8, c.v. = 2.3.

Year - the linear decline and quadratic contrasts are significant, and there are differences between years.

Year	1982	1983	1984	1985	1986
Sat %	110c	92b	84a	77a	79a

n = 45, s.e. = 1.8, c.v. = 7.1.

Year x Treatment, see Figure 15.
Year x Amendment, see Figure 16.

EC (mS/cm)

Amendment	Ash	Gypsum	Control
EC	6.0a	7.7c	6.8b

n = 75, s.e. = 0.19, c.v. = 0.7.

Year - linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
EC	5.0	6.6	7.3	7.6	7.8

n = 45.

Year x Treatment, see Figure 17.

Na (me/L)

Amendment	Ash	Gypsum	Control
Na	57a	75c	64b

n = 75, s.e. = 1.91, c.v. = 6.8.

Year - linear and quadratic contrasts are significant

Year	1982	1983	1984	1985	1986
Na	44	67	81	69	67

Year x Treatment, see Figure 18.
Year x Amendment, see Figure 19.

SAR

Year - the quadratic contrast is significant.

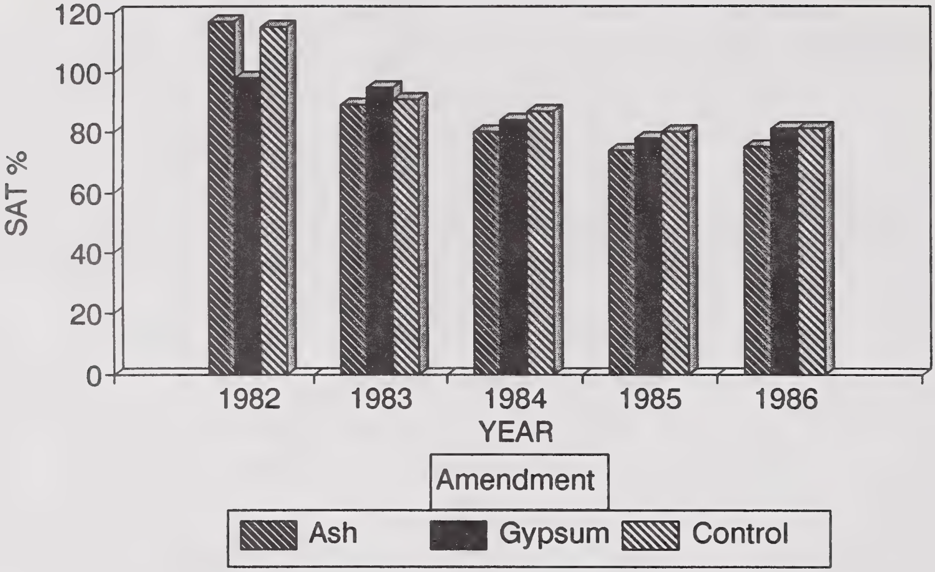
Year	1982	1983	1984	1985	1986
SAR	16	19	21	18	17

n = 45.

Importance of interactions is summarized as follows:

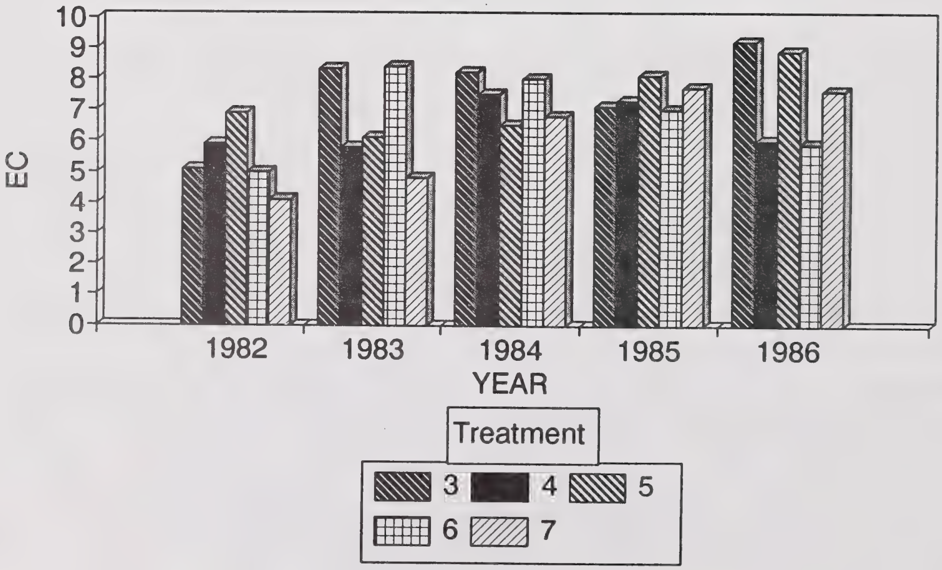
1. Ash amended plots usually had lowest saturation percentages except in 1982 when they were highest; however, differences among amendments in the last 4 years were less than 10% and are not significant (Figure 16).
2. While the overall pattern was one of increasing EC then levelling off, important differences in EC levels between treatments are evident (Figure 17);
   a. Treatment 3 increased in 1983 then levelled off;
   b. Treatment 4 was constant 2 years, then increased 1 year, then decreased 2 years;
   c. Treatment 5 decreased in 1983, then increased 3 years;
   d. Treatment 6 increased in 1983, then decreased 3 years, but was still above original levels; and
   e. Treatment 7 steadily increased, then levelled off in the last year;
   f. in summary, Treatments 4 and 6 were improving in the last three years while Treatments 3, 5 and 7 were degrading.
3. Na levels by treatment followed a similar pattern to EC levels over the five year period (Figure 18).
4. On ash amended and control plots, Na levels increased till 1984 then decreased, while on gypsum plots Na increased till 1984, decreased in 1985, then increased again (Figure 19).

Soil quality rating for upper subsoils was Unsuitable in 1986 due to excessive SAR, but in the latter years the trend was towards improvement. Saturation percentage and EC remained within the Fair category for most treatments. The presence of lime and salts tends to prevent soil dispersion and to mitigate harmful effects of excessive SAR. If leaching continues the soil could gradually improve with both SAR and EC declining. A decline in SAR and little change in EC in upper subsoils while topsoil salts were leached through indicates favorable root zone development.



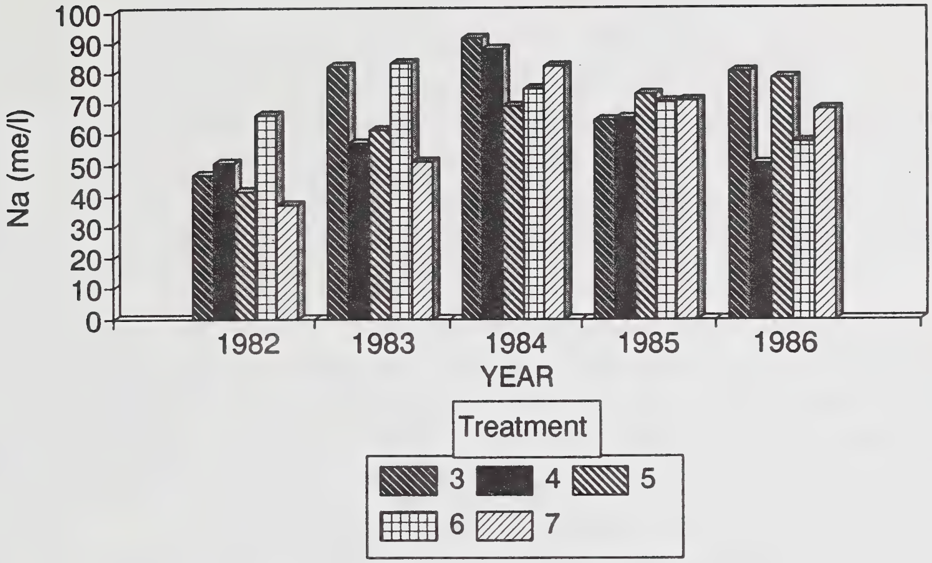
n = 15, s.e. = 3.1, c.v. = 15.2.

Figure 16. Upper subsoil saturation percentage by year and amendment, Torlea Soil Experiment, 1982 to 1986.



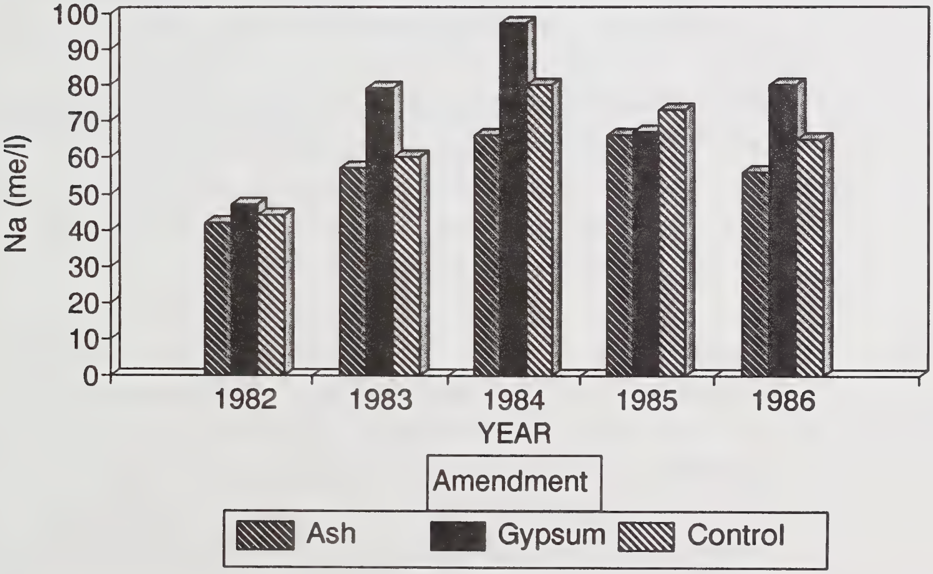
n = 9, s.e. = 0.59, c.v. = 3.

Figure 17. Upper subsoil EC by year and treatment, Torlea Soil Experiment, 1982 to 1986.



n = 9, s.e. = 6.91, c.v. = 27.

Figure 18. Upper subsoil Na by year and treatment, Torlea Soil Experiment, 1982 to 1986.



n = 15, s.e. = 3.5, c.v. = 20.5.

Figure 19. Upper subsoil Na by year and amendment, Torlea Soil Experiment, 1982 to 1986.

2.2.4.3 Lower subsoils. Significant changes occurred only in response to time (Table 26). Saturation percentage decreased substantially from 1982 to 1983 then declined gradually. EC increased, then levelled off. Na and SAR initially increased, peaked in 1984, then declined. Lower subsoil quality was Unsuitable throughout the monitoring period due to excessive SAR. Increases in EC combined with decreases in Na are attributed to leaching of salts from upper horizons. If Na was rising from spoil, then SAR should have increased.

2.2.4.4 Lower minus upper Torlea subsoils. Differences are evident (Table 27): treatment, amendment, and time effects occurred indicating that upper subsoils were significantly different from lower subsoils even though both were within the Unsuitable category due to high SAR levels. Overall comparisons of all treatments and amendments combined indicate EC, Na and SAR to be greater in the lower subsoil than the upper subsoil.

Treatment effects are reflected in saturation percentage and SAR. In Treatment 4, upper subsoil has lower saturation percentage than lower subsoil: the opposite is true for Treatment 6. Treatment 4 had the greatest SAR difference between upper and lower subsoils, being more favourable in the upper layer. In Treatment 7, there was less than 1 unit difference in SAR between the layers.

Amendment effects are reflected in EC such that the smallest difference was within control plots and the largest difference was in ash amended plots. Differences in Na levels were also most pronounced in ash plots but lowest in gypsum amended plots. These are important findings and they are discussed in greater detail in Section 3.

2.2.5 Soil Moisture

As in the Subsoil Depth Experiment, soil moisture content was measured monthly through the growing season, by neutron probe. Major factors considered in gathering and interpreting moisture data included:

1. moisture availability to plants and depth of rooting;
2. occurrence of saturated conditions, or perched water table; and
3. effects of moisture on soil development.

Table 26. Lower subsoil salinity, Torlea Soil Experiment, 1982 to 1986.

Saturation %

Year - the linear decline and the quadratic contrasts are significant.

Year - there are differences between years as indicated.

Year	1982	1983	1984	1985	1986
Sat%	115c	88b	87b	76a	81ab

n = 36, s.e. = 2.5, c.v. = 10.

EC (mS/cm)

Year - the linear and quadratic contrasts are significant, indicating that increases in EC are levelling off.

Year	1982	1983	1984	1985	1986
EC	5.9	8.3	8.7	8.9	9.2

n = 36.

Na (me/L)

Years - both the linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
Na	54	83	101	82	81

n = 36.

SAR

Year - only the quadratic contrast is significant.

Year	1982	1983	1984	1985	1986
SAR	17	19	24	19	19

n = 36.

Table 27. Lower subsoil (SS2) minus upper subsoil (SS1) salinity, Torlea Soil Experiment, 1982 to 1986.

Saturation %

Treatment	4	5	6	7
Sat %	14b	1.5ab	-14a	-5ab

n = 45, s.e. = 5.2, c.v. = 25.3.

Year x Treatment

Treatment	1982	1983	1984	1985	1986
4 B & upper C	25e	7bcde	14cde	6bcde	16de
5 C	0abcde	6bcde	4bcde	9bcde	6bcde
6 C	-29a	-16abc	-12abcd	-10abcd	-6abcde
7 C and ash	12cde	-20ab	-3abcde	-1abcde	-15abc

n = 9, s.e. = 5.9, c.v. = 31.

EC (mS/cm)

Amendment	Ash	Gypsum	Control
SS2-SS1	2.3b	1.5ab	0.75a

n = 60, s.e. = 0.32, c.v. = 1.2.

Overall difference: n = 180, SS2 (8.2) - SS1 (6.7) = 1.5

Na (me/L)

Amendment	Ash	Gypsum	Control
SS2-SS1	24b	9a	16ab

n = 60, s.e. = 3.96, c.v. = 14.

Overall difference: n = 180, SS2 (80) - SS1 (64) = 16.

SAR

Treatment	4	5	6	7
SS2-SS1	4.3b	1.3ab	1.4ab	-0.8a

n = 45, s.e. = 0.83, critical value = 4.1.

Overall Difference: n = 180, SS2 (19.6) - SS1 (18.1) = 1.5

As an aid to interpreting moisture measurements, special studies on moisture availability were conducted in 1987 and results are given in Table 28.

To summarize the five year data, soil moisture classes were developed indicating droughty (wilting point plus 5% moisture) and readily available (remaining available moisture) soil moisture levels for crop growth. The frequency of occurrence of months with adequate moisture content based on field monitoring was then tabulated, and is shown in Table 29.

Differences in moisture content between ash, gypsum and control treatments are clear in Table 29. Ash amended topsoils had adequate plant available moisture 55 to 75% of months, compared to 15 to 55% for the gypsum treatment and the controls. This assumes that the ash does not distort the probe readings. Subsoils appear slightly wetter in controls than in gypsum or ash amended treatments, possibly reflecting shallower rooting depths and lower crop extraction from the former.

Maximum moisture levels seldom exceeded field capacity and never approached saturation percentage. This indicated an absence of water tables within the monitoring depths. Driest moisture levels observed during monthly monitoring on Torlea topsoils and subsoils were about 10% less than those reported in Table 28. This implies that the measured wilting point does not accurately reflect field conditions and, therefore, the soils were not as droughty as suggested by Table 29. The wilting point moisture content used for spoil matches the lowest readings observed during monthly monitoring.

2.2.6 Bulk Density

Bulk density data from selected layers taken in 1983, 1985, 1986 and 1987 are presented in Table 30. Topsoil, upper subsoil, lower subsoil and deep spoil are compared and readings were chosen so as to avoid possible erroneous measurements due to material mixes.

Topsoil densities are similar for all treatments and amendments and ranged from about 1.0 to 1.2 g/cm^3 except they were considerably higher in 1985 than before or after. This is likely due to differences in calibration rather than to soil changes. Upper subsoil densities appear to have decreased slightly from 1983 to 1987, with a peak in 1985.

Table 28. Soil moisture availability, Torlea Soil Experiment, 1987.

	Bulk Density (g/cm^3)	Wilting Point (WP) (Wt.%)	Wilting Point (WP) (Vol.%)	Field Capacity (FC) (Wt.%)	Field Capacity (FC) (Vol.%)	FC - WP (Vol.%)
Topsoil[a]	1.10	20	22	36	40	18
Subsoil[b]	1.38	21	29	34	47	18
Spoil[c]			29		47	18

[a] Based on mean of 15 samples from control

[b] Based on mean of 30 samples from control

[c] Treated as equivalent to subsoil for making comparisons; however, the absolute values are probably meaningless due to high sodicity. If WP and FC of spoil could be determined, they would be much higher.

Table 29. Percentage of months with moisture content readily available to plants[a], May to September, Torlea Soil Experiment, 1982 to 1986.

Treatment	Material[b]	Depth (cm)	Ash	Gypsum	Control
1	SP	0 to 15	60%	13%	33%
	SP	60 to 75	7	47	93
2	TS	0 to 15	73	47	53
	SP	15 to 30	20	0	0
	SP	80 to 95	100	93	100
3	TS	0 to 15	47	33	27
	SS	15 to 30	0	33	20
	SP	40 to 55	20	7	0
	SP	100 to 115	27	53	0
4	TS	0 to 15	60	27	33
	SS	15 to 30	0	13	13
	SS	40 to 55	13	0	0
	SS[c]	60 to 75	7	0	0
	SP	120 to 135	73	7	67
5	TS	0 to 15	67	27	33
	SS	15 to 30	0	20	20
	SS	40 to 55	0	0	7
	SS	60 to 75	0	0	0
	SS[c]	80 to 95	0	13	13
	SP	120 to 135	33	93	67
6	TS	0 to 15	73	40	33
	SS	15 to 30	0	13	27
	SS	40 to 55	0	0	20
	SS	60 to 75	0	0	20
	SS[c]	80 to 95	0	7	13
	SP	120 to 135	13	93	27
7	TS	0 to 15	53	13	33
	SS	15 to 30	0	0	7
	SS	40 to 55	0	13	33
	SS[c]	60 to 75	47	27	20
	ASH[c]	80 to 95	20	33	0
	SP[c]	120 to 135	0	0	93

[a] TS = greater than 25% moisture, SS and SP = greater than 26% moisture (see Table 28).

[b] TS=Topsoil, SS=Subsoil, SP=Spoil

[c] Possible composite of materials.

Table 30. Selected bulk density values (g/cm^3), Torlea Soil Experiment.

	1983			1985			1986			1987		
	Ash	Gypsum	Control	Ash	Gypsum	Control	Ash	Gypsum	Control	Ash	Gypsum	Control
1. Topsoil (Trts 2 to 7) n = 18	0.90	1.02	1.10	1.46	1.39	1.41	1.18	0.91	1.02	1.16	1.10	1.12
2. Upper Subsoil (Trts 4 to 7) n = 12	1.40	1.36	1.48	1.38	1.54	1.56	1.17	1.17	1.28	1.03	1.15	1.08
3. Lower Subsoil (Trts 4 to 7) n = 12	1.45	1.43	1.45	1.58	1.53	1.67	1.45	1.34	1.36	1.38	1.31	1.15
4. Spoil (Trts 1 to 7) n = 21	1.45	1.43	1.45	1.65	1.61	1.62	1.45	1.39	1.41	1.38	1.25	1.31

Source: BRSRP unpublished annual reports.
Bulk Density determined by density probe and corrected to dry wt. by subtracting percentage moisture.

Lower subsoil and spoil densities are similar and they do not differ appreciably among Treatments or in response to amendments. Variations over time may be due to calibration errors rather than to soil changes. Bulk densities of lower subsoils and spoil were around 1.45 g/cm^3 in 1983, increased, then decreased to around 1.30 g/cm^3 in 1987.

2.2.7 Root Distribution

All topsoils in Treatments 2 to 7 contained plentiful to abundant fine and very fine roots. Roots generally penetrated no more than 15 cm into spoil or to a maximum depth of about 130 cm. Amendment effects were clear in Treatment 1 (spoil); in that the ash amended plots had much more forage growth and more roots than gypsum and control plots. In other treatments, effects of amendments were not well defined; however, it appeared that gypsum promoted deeper rooting in Treatment 6. Specific findings for each treatment are summarized below:

1. Treatment 1 (spoil): There were few roots in the upper 25 cm of the gypsum and control plots whereas in the ash amendments they were plentiful in the upper 10 cm and few to about 25 cm.
2. Treatment 2 (20 cm topsoil over spoil): Roots were plentiful to abundant in the topsoil, few to about 30 cm (upper spoil), very few to 100 cm, and none below.
3. Treatment 3 (20 cm topsoil, 20 to 30 cm B+C, spoil): Roots were plentiful to abundant in the topsoil, plentiful in the subsoil to about 35 cm, and few in the upper 15 cm of spoil. Some roots extended down to 100 cm. There appeared to be an amendment effect in that rooting was deeper under gypsum, than ash or control.
4. Treatment 4 (20 cm topsoil, 45 to 55 cm B+C, spoil): Roots were plentiful to abundant in the topsoil, plentiful in the subsoil to about 60 cm, few in the upper spoil, and none in the spoil below about 130 cm.

5. Treatment 5 (20 cm topsoil, 75 to 90 cm C, spoil): Roots were plentiful to abundant in the topsoil, plentiful in the subsoil to about 50 cm, very few to 15 cm below the spoil contact, and none below.
6. Treatment 6 (20 cm topsoil, 100 to 115 cm C, spoil): Roots were plentiful to abundant in the topsoil, plentiful in the subsoil to about 45 cm, few to 60 cm, and very few in the upper spoil, but none below about 130 cm. Plentiful rooting in ash and gypsum amended plots was slightly deeper than in the control plots.
7. Treatment 7 (20 cm topsoil, 45 to 60 cm C, 20 to 35 cm ash, spoil): Roots were plentiful to abundant in the topsoil, plentiful in the upper subsoil to about 40 cm, few to about 100 cm, and very few to about 120 cm.

2.3 BOTTOM ASH EXPERIMENT

2.3.1 Objectives

The objective of this experiment is to assess the potential of bottom ash as a capillary barrier to upward movement of sodium salts from mine spoil into replaced subsoil. Forage and grain yields, chemical properties, moisture levels and soil densities were assessed with regard to the following treatments on three replicates.

Treatment	Layer Thickness
1	15 cm topsoil/25 cm subsoil/spoil
2	15 cm topsoil/25 cm subsoil/gypsum/spoil
3	15 cm topsoil/25 cm subsoil/5 cm ash/spoil
4	15 cm topsoil/25 cm subsoil/15 cm ash/spoil
5	15 cm topsoil/25 cm subsoil/45 cm ash/spoil

The null hypotheses are:

1. Crop production is not affected by addition of bottom ash buffer layers between replaced subsoil and sodic spoil. If rejected identify optimal thickness of bottom ash layer.
2. Crop production is not affected by addition of a gypsum layer between replaced subsoil and sodic spoil. If rejected, quantify the effect.

3. Grain and forage crops will not respond differently to bottom ash or gypsum layers between replaced subsoil and sodic spoil. If rejected, quantify the effect.

Plot layout is illustrated in Figure 20. Soils were sampled at one location per plot and yields were measured on a 4 m x 7 m central portion of each plot.

2.3.2 Statistical Analysis

Forage and grain yields were analyzed separately as a split-plot experiment in time, with treatments as the main plot factor and year as the sub-plot factor. Year main effects were decomposed into planned linear and quadratic contrasts using coefficients from standard tables (Snedecor and Cochran 1980). Chemical data were analyzed as a split-split-plot experiment, with treatments as the main plot factor, crop as the sub-plot factor and year as the sub-subplot factor. The ANOVA tables for the statistical analyses of crop and soils data are shown in Table 31.

Treatment main effects were decomposed into linear and quadratic planned contrasts (using coefficients as calculated from Myers 1979). These contrasts indicate whether there is a linear change in soil chemistry with increasing depth of ash or whether there is curvature to the relationship (i.e. increase to a point then decrease or vice-versa). In addition, the gypsum treatment (2) was contrasted with the control (1). For additional post hoc tests Tukey's HSD at p=0.05 was used.

Year main effects were decomposed into planned linear and quadratic contrasts using coefficients from standard tables (Snedecor and Cochran 1980). For spoil, the chemical analyses were conducted over the 1984 to 1986 period due to missing data in the previous years.

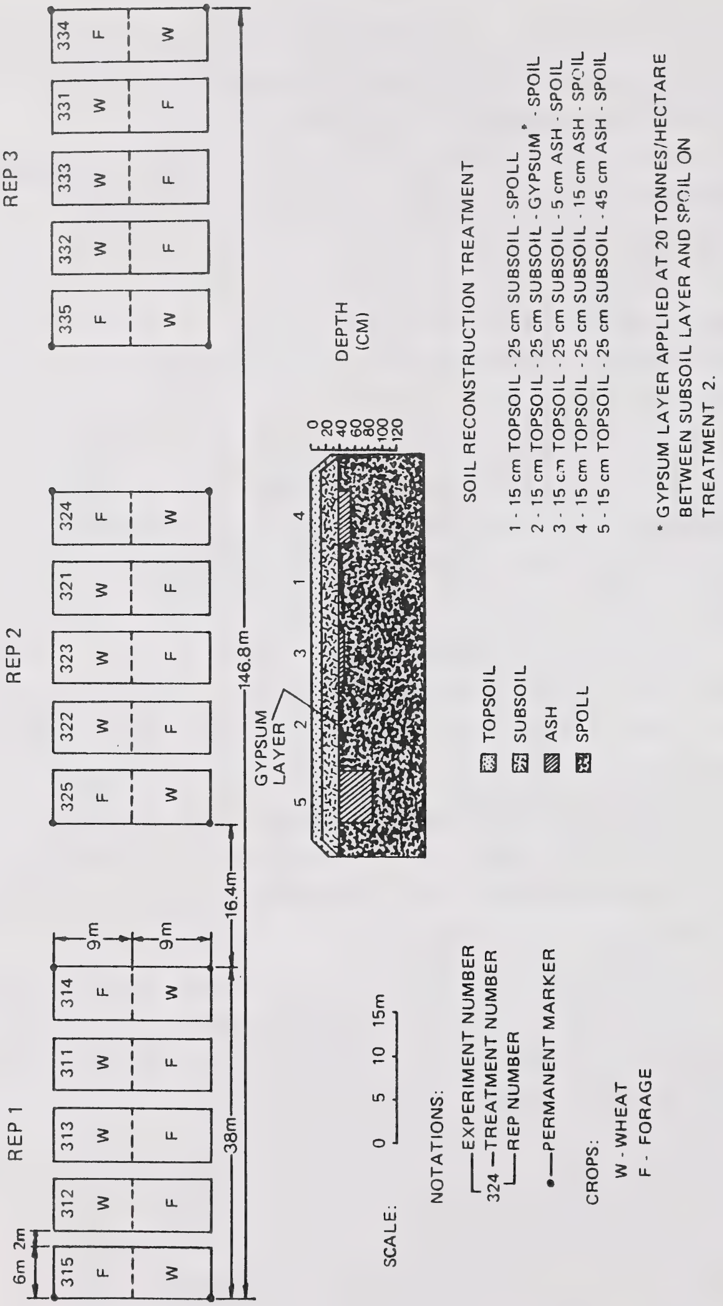

REP 1
REP 2
REP 3
315 F W
312 W F
313 W F
311 W F
314 F W
325 F W
322 W F
323 W F
321 W F
324 F W
335 F W
332 W F
333 W F
331 W F
334 F W
6m
2m
9m
9m
38m
16.4m
146.8m
GYPSUM LAYER
5 2 3 1 4
0 20 40 60 80 100 120
DEPTH (CM)
SCALE:
0 5 10 15m
NOTATIONS:
324 — EXPERIMENT NUMBER
— TREATMENT NUMBER
— REP NUMBER
● — PERMANENT MARKER
CROPS:
W - WHEAT
F - FORAGE
▨ TOPSOIL
▨ SUBSOIL
▨ ASH
▨ SPOIL
SOIL RECONSTRUCTION TREATMENT
1 - 15 cm TOPSOIL - 25 cm SUBSOIL - SPOLL
2 - 15 cm TOPSOIL - 25 cm SUBSOIL - GYPSUM* - SPOIL
3 - 15 cm TOPSOIL - 25 cm SUBSOIL - 5 cm ASH - SPOIL
4 - 15 cm TOPSOIL - 25 cm SUBSOIL - 15 cm ASH - SPOIL
5 - 15 cm TOPSOIL - 25 cm SUBSOIL - 45 cm ASH - SPOIL
* GYPSUM LAYER APPLIED AT 20 TONNES/HECTARE BETWEEN SUBSOIL LAYER AND SPOIL ON TREATMENT 2.

Figure 20. Plot layout, Bottom Ash Experiment.

Table 31. ANOVA tables for crop and soil analyses, Bottom Ash Experiment.

CEREAL (Forage has 1 yr. less)

Source of Variation	Degrees of Freedom	
Replicate (R)	(R - 1) = 2	
Treatment (T)	(T - 1) = 4	
Linear contrast		(1)
Quadratic contrast		(1)
Error	(R - 1)(T - 1) = 8	
Year (Y)	(Y - 1) = 4	
Linear contrast		(1)
Quadratic contrast		(1)
Year x Treatment	(Y - 1)(T - 1) = 16	
Error	(T - 1)(Y - 1)(R - 1) = 32	

SOILS

Effects	Degrees of Freedom	Appropriate Error
Whole Plot		
Treatment (T)	4	TR
Replicate (R)	2	
TR	8[a]	
Split Plot		
Crop (C)	1	CR
CT	4	CTR
CR	2[a]	
CTR	16[a]	
Split Split Plot		
Year (Y)	4	YR
YT	20	YTR
YC	4	YCR
YTC	16	YTCR
YR	8[a]	
YTR	32[a]	
YCR	8[a]	
YTCR	32[a]	

[a] Error

2.3.3 Bottom Ash Yields

Forage yields measured, on a dry weight basis, each July, 1983 to 1986, were statistically analyzed and it was found that year is the only significant factor affecting yields. Likewise, a wheat nurse crop harvested in 1982 showed no treatment responses. In 1983, forage yields were higher than subsequently and there was a significant linear decline with time but no year to year differences as follows:

Year	1983	1984	1985	1986
kg/ha	2869a	2094a	2213a	1842a

n = 15, s.e. = 106, c.v. = 108.

Treatment differences were not significant and forage yields were as follows:

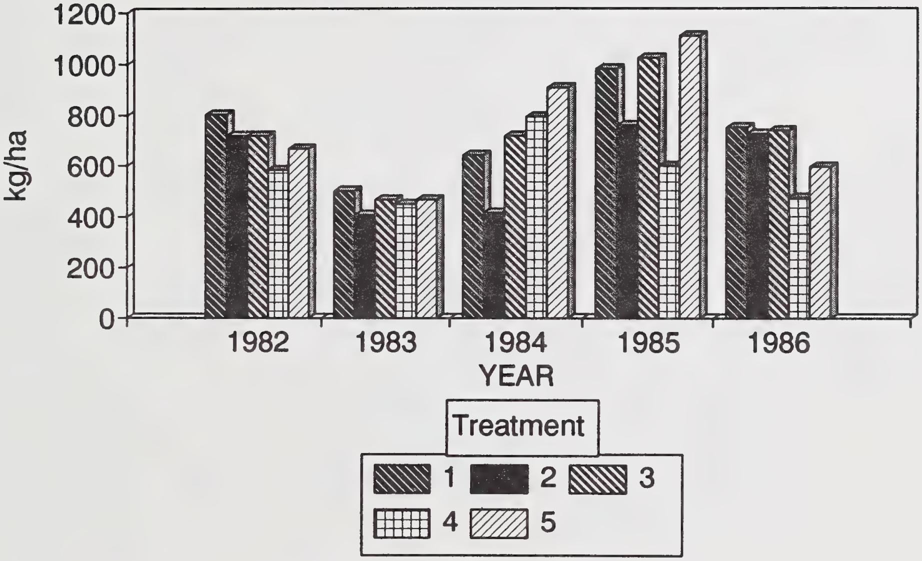
Treatment	1	2	3	4	5
kg/ha	2015	1974	2416	2204	2892

Grain yield analysis indicated that there were no significant (at $p = 0.05$) responses to treatment or to year; however, at a lower level of significance ($p = 0.10$) treatment, year and their interaction were all significant. Figure 21 shows this pattern.

2.3.4 Bottom Ash Soil Salinity Analysis

The main statistical findings of this experiment are summarized in Table 32. Important changes occurred in the topsoils and subsoils over time: topsoils improved while subsoils degraded then began to improve. Topsoil quality was also affected by crops such that forage plot soils were slightly better than soils under cereal crops. Effects of treatments were most pronounced in the spoil layer.

2.3.4.1 Topsoil. Characteristics changed with respect to all parameters measured (Table 33). Saturation percentage steadily decreased the first two years then stabilized. EC, Na and SAR levels all increased until 1983 then declined to values below original levels. An analysis of topsoil quality versus bottom ash thickness reveals that topsoil in Treatment 4 (15 cm ash)



n = 3, s.e. = 87, c.v. = 480 kg.

Figure 21. Cereal yields, Bottom Ash Experiment, 1982 to 1986.

Table 32. Statistical summary for Bottom Ash Experiment, salinity data, 1982 to 1986.

Layer Parameter	Tmt	Crop	Tmt x Crop	Yr	Yr x Tmt	Yr x Crop	Overall
Topsoil							
Sat %				*			
EC	*	*		*			
Na		*		*			
SAR		*		*		*	
Subsoil							
Sat %				*			
EC				*		*	
Na				*		*	
SAR			*	*			
Spoil							
Sat %							
EC	*						
Na	*			*			
SAR				*			
Spoil - Subsoil							
Sat %		*					*
EC		*					*
Na		*	*				*
SAR						*	*

Table 33. Topsoil salinity, Bottom Ash Experiment, 1982 to 1986.

Saturation %

Both linear and quadratic contrasts are significant and indicate a decline in time, mostly in the first two years.

Year	1982	1983	1984	1985	1986
Sat %	38c	36b	33a	33a	33a

n = 30, s.e. = 0.51, c.v. = 2.0.

EC (mS/cm)

Crop - cereal (2.8) > forage (2.2), n = 75.
Year - the linear decline and curvature over time are significant.

Year	1982	1983	1984	1985	1986
EC	2.8	3.3	2.9	2.3	1.5

n = 30.

Treatment - The planned quadratic comparison for depths of bottom ash is significant.

Treatment	3	4	5
EC	2.4	3.1	2.5

n = 30. No differences between treatments.

Na (me/L)

Crop - cereal (13.4) > forage (9.8), n = 75.
Year - both the linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
Na	11.4abc	16.9c	15.4bc	8.8ab	5.3a

n = 30, s.e. = 1.7, c.v. = 6.8.

SAR

Crop - cereal (3.8) > forage (2.9), n = 75.
Year - linear and quadratic contrasts are significant and indicate a decline with time.

Year	1982	1983	1984	1985	1986
SAR	3.4	4.2	4.1	2.8	2.3

n = 30.

Year x Crop

Year	1982	1983	1984	1985	1986
Cereal	3.4abcd	5.1d	3.9abcd	3.9abcd	2.7abc
Forage	3.5abcd	3.3abcd	4.3cd	1.7a	2.0ab

n = 15, s.e. = 0.49, c.v. = 2.27.

had slightly higher EC levels than Treatments 3 (5 cm ash) and 5 (45 cm ash). EC, Na and SAR values were all slightly higher under cereals than under forages; regardless, topsoil quality was Fair the first three years and Good the last two years.

2.3.4.2 Subsoil. Saturation percentages declined initially then stabilized in 1984: EC, Na and SAR increased initially, peaked in 1984, then declined to values slightly greater than those of 1982 (Table 34). The only significant treatment effect found was in comparing the control and gypsum treatments in that the latter had slightly higher SAR levels.

Subsoil quality in 1986 was rated Poor in terms of EC, and Unsuitable due to excessive SAR (13). Note that in this experiment there was no distinction between upper and lower subsoils as in the other experiments: the interval sampled included both.

2.3.4.3 Spoil. There were spoil changes in response to treatment and year (Table 35). Saturation percentage and SAR were greater for the control than the gypsum treatment suggesting that gypsum moved downward into the spoil. EC and Na levels in spoil decreased with increasing thickness of bottom ash. Time was also important: from 1984 to 1986 Na levels declined and levelled off. As in all other experiments, spoil quality was Unsuitable due to excessive SAR.

2.3.4.4 Spoil minus subsoil. Differences indicate the expected: saturation percentage and SAR were much greater in spoil while EC and Na levels were greater in subsoil (Table 36). In addition, there were treatment effects, such that, gypsum reduced the difference in saturation percentage and SAR, compared to the control. Crop effects were reflected in EC and Na with greater differences occurring under forage. Some interactions are also significant. Under forage, Treatment 1 was the only case in which spoil Na levels exceeded those of subsoil. Treatment 3 forage and Treatment 2 cereal plots had the greatest Na concentrations in the subsoil relative to spoil. During 1984 to 1986 the differences were constant under forage but decreased under cereal.

Table 34. Subsoil salinity, Bottom Ash Experiment, 1982 to 1986.

Saturation %

Year - there is a linear decline with time.

Year	1982	1983	1984	1985	1986
Sat %	48b	44a	42a	42a	42a

n = 30, s.e. = 0.87, c.v. = 3.4.

EC (mS/cm)

Year - there is a significant increase with time.

Year	1982	1983	1984	1985	1986
EC	6.8	7.2	8.4	7.4	7.9

n = 30.

Year x Crop

Year	1982	1983	1984	1985	1986
Cereal	7.3abc	6.9ab	8.1bc	7.6bc	8.0bc
Forage	6.2a	7.5abc	8.6c	7.2abc	7.9bc

n = 15, s.e. = 0.24, c.v. = 1.4.

Na (me/L)

Year - both the linear increase and the quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
Na (me/L)	48	57	80	57	62

n = 30.

Year x crop - differences are significant.

Year	1982	1983	1984	1985	1986
Cereal	54ab	53a	77bc	60ab	62abc
Forage	42a	62abc	83c	54ab	62abc

n = 15, s.e. = 3.87, c.v. = 23.

SAR

Year - the linear and quadratic contrasts are significant.

Year	1982	1983	1984	1985	1986
SAR	10	12	16	13	13

n = 30.

The planned comparison of Treatment 1 (control) vs. Treatment 2 (gypsum) is significant.

Treatment	1	2
SAR	11	15

n = 30.

Table 35. Spoil salinity, Bottom Ash Experiment, 1984 to 1986.

Saturation %

Treatment - The planned comparison is significant.

Treatment	1 Control	2 Gypsum
Sat %	151	136

n = 30.

EC (mS/cm)

Treatment - the linear decline in EC with increasing depth of bottom ash is significant (Treatments 3 to 5).

Treatment	1	2	3	4	5
EC	5.5	6.1	5.5	4.6	4.3

n = 30.

Na (me/L)

Treatment - the linear decline with increasing depth of bottom ash is significant (Treatments 3 to 5).

Treatment	1	2	3	4	5
Na	56	61	55	47	43

n = 30.

Year - the planned quadratic contrast over time is significant.

Year	1984	1985	1986
Na	60	46	52

n = 30.

SAR

Year - the linear and quadratic contrasts are significant.

Year	1984	1985	1986
SAR	37	32	31

n = 30.

Treatment - although the overall treatment effects are not significant, the planned comparison of Treatments 1 (Control) and 2 (Gypsum) are.

Treatment	1	2
SAR	36	29

n = 30.

Table 36. Spoil (Sp) minus Subsoil (SS) salinity, Bottom Ash Experiment, 1984 to 1986.

Saturation %

Treatment - the planned comparison of Treatment 1 versus Treatment 2 is significant.

Treatment	1	2	3	4	5
Sat %	110	92	101	107	104

n = 18.

Overall difference: n = 90, Sp (147) - SS (44) = 103.

EC (mS/cm)

Crop - cereal (-2.5) > forage (-2.9), n = 45.

Overall difference: n = 90, Sp (5.2) - SS (7.9) = -2.7.

Na (me/L)

Crop - cereal (-12) > forage (-16).

Crop x Treatment

Treatment	1	2	3	4	5
Cereal	-6.4ab	-28a	-11ab	-9ab	-5ab
Forage	3.9b	-9.6ab	-36a	-16ab	-24ab

n = 9, s.e. = 5.4, c.v. = 31.7.

Overall difference: n = 90, Sp (52.4) - SS (66.4) = -14.

SAR

Year x Crop

Year	1984	1985	1986
Cereal	22b	20ab	17a
Forage	19ab	19ab	19ab

n = 15, s.e. = 0.65, c.v. = 4.4.

Treatment - the planned comparison of Treatment 1 versus 2 is significant.

Treatment	1	2	3	4	5
SAR	23	12	17	20	23

n = 18.

Overall difference: n = 90, Sp (33.3) - SS (14.3) = 19.

2.3.5 Soil Moisture

As in other experiments, soil moisture percentage was measured monthly through the growing season using a neutron probe. Major factors considered in gathering and interpreting moisture data included:

1. moisture availability to plants and depth of rooting;
2. occurrence of saturated conditions, or perched water table; and
3. effects of moisture on soil development.

As an aid to interpreting moisture measurements, special studies on moisture availability were conducted in 1987 and results are given in Table 37. Driest moisture levels in topsoils and subsoils were 10 and 19%, respectively, and these values are very close to lab results (Table 37).

To summarize the five year data, soil moisture classes were developed as described previously, indicating droughty (wilting point plus 5%) and readily available (remaining available moisture) soil moisture levels for crop growth. The frequency of occurrence of months with readily available moisture as determined from examination of field data is summarized in Table 38. From Table 38, average available moisture in topsoil and subsoil varied between treatments as follows:

Trt 2 (gypsum) > Trt 1 (control) and Trt 3 (5 cm ash) >
Trt 4 (15 cm ash) and Trt 5 (45 cm ash).

All treatments were drier under forages than under cereals.

2.3.6 Bulk Density

Bulk densities were measured in 1983, 1985, 1986 and 1987 using a density probe; selected values are presented in Table 39. Data are chosen so as to exclude buried ash layers, and to exclude readings in the vicinity of material interfaces. Measurements presented and analyzed therefore represent topsoil, subsoil and spoil at comparable depths over a period of time.

Topsoil densities were quite variable, ranging from 1.70 g/cm^3 in 1983 to 1.30 g/cm^3 in 1986. Average values in 1987 were 1.42 and 1.44 g/cm^3 for cereals and forages, respectively.

Table 37. Soil moisture availability, Bottom Ash Experiment.

	Bulk Density (dry)	Wilting Point (Wt.%)	Wilting Point (Vol.%)	Field Capacity (Wt.%)	Field Capacity (Vol.%)	Availability FC-WP (Vol.%)
Topsoil[a]	1.3	9	12	18	24	12
Subsoil[b]	1.7	12	20	23	39	19
Spoil[c]			20		39	19
Buried Ash[d]			10		14	4

[a] Based on mean of 15 samples

[b] Based on mean of 30 samples

[c] Treated as equivalent to subsoil for making comparisons. If WP and FC of spoil could be determined, values would probably be much higher.

[d] Based on mean of 5 samples

Table 38. Percentage of months with moisture content readily available to plants[a], May to September, Bottom Ash Experiment, 1982 to 1986.

Treatment	Material[b]	Depth (cm)	Cereal	Forage
1	TS	0 to 15	47%	13%
	SS	15 to 30	33	20
	SP	40 to 55	93	67
	SP	85 to 100	100	100
2	TS	0 to 15	47	33
	SS	15 to 30	67	47
	SP	40 to 55	100	73
	SP	85 to 100	93	100
3	TS	0 to 15	47	27
	SS	15 to 30	33	13
	SS	40 to 55	20	27
	SP[c]	60 to 75	93	100
	SP	85 to 100	93	100
4	TS	0 to 15	40	20
	SS	15 to 30	0	0
	ASH	40 to 55	7	0
	SP	60 to 75	100	73
	SP	85 to 100	80	93
5	TS	0 to 15	53	27
	SS	15 to 30	7	7
	ASH[c]	40 to 55	0	0
	ASH[c]	60 to 75	0	0
	SP	85 to 100	67	0

[a] TS = greater than 14% moisture, SS and SP = greater than 17% moisture (see Table 37).

[b] TS=Topsoil, SS=Subsoil, SP=Spoil   [c] Possible composite of materials.

Table 39. Selected bulk density values (g/cm^3), Bottom Ash Experiment.

	1983		1985		1986		1987	
Material	Cereal	Forage	Cereal	Forage	Cereal	Forage	Cereal	Forage
1. Topsoil (Trts 1 to 4) n = 12	1.67	1.70	1.47	1.46	1.33	1.30	1.42	1.44
2. Upper Subsoil (Trts 1 to 4) n = 12	1.87	1.90	1.59	1.76	1.63	1.69	1.59	1.70
3. Lower Subsoil (Trts 3 to 6) n = 12	1.67	1.60	1.56	1.51	1.57	1.53	1.60	1.50

Subsoil densities were highest in 1983, about 1.90 g/cm^3, and decreased to 1.59 g/cm^3 and 1.70 g/cm^3 for cereals and forages, respectively, by 1987. Differences between crops are not significant, but changes over time may be. While the data indicate a decline, the reliability of the calibrations and calculations is questionable.

Spoil densities were somewhat lower, averaging 1.67 and 1.60 g/cm^3 in 1983 and declining to 1.60 and 1.50 g/cm^3 by 1987 for cereals and forages, respectively.

In 1987, soil cores were taken to determine bulk densities of the upper soil horizons in Replicate 2. Results of the gravimetric determinations and comparable density probe values are summarized as follows:

Layer	Mean Bulk Density, Cores (g/cm^3)	Mean Bulk Density, Probe Values (g/cm^3)
Topsoil (0 to 15 cm)	1.32	1.44
Subsoil (15 to 30 cm)	1.76	1.64
Subsoil (30 to 45 cm)	1.75	1.66
Number of samples/mean	20	30

The discrepancies of about 0.10 g/cm^3 between gravimetric and probe results for topsoils and subsoils make the probe values suspect. Regardless, densities in 1987 were excessively high for good root growth.

2.3.7 Root Distribution

Root growth as observed in the forage plots in 1985 and 1986 is summarized as follows:

1. Treatment 1: Plentiful to abundant fine and very fine roots to 25 cm; few roots in remaining subsoil and upper 15 cm of spoil; no roots deeper.
2. Treatment 2 to 5: Plentiful to abundant fine and very fine roots to about 35 cm; few roots in lower subsoil, ash layer and upper 15 cm of spoil; no roots deeper.

In the cereal plots, roots were: plentiful to abundant in topsoils of all treatments; few in the subsoil or ash layers to about 40 cm; very few down to 15 cm into spoil; and none deeper.

2.4 SLOPE DRAINAGE EXPERIMENT

2.4.1 Objectives

This experiment is designed to determine the effect of degree of spoil levelling (slope) and aspect (north vs south) on salt movement and productivity of forage crops. Plot layout is illustrated in Figure 22. Reconstruction profiles consist of 15 cm of topsoil (A horizon) over 50 cm of subsoil over spoil. Treatments consist of a combination of 5 and 10 degree slopes with northern and southern aspects on two replicates and are as follows:

Treatment
1 5 degree slope - north aspect (5° N)
2 10 degree slope - north aspect (10° N)
3 5 degree slope - south aspect (5° S)
4 10 degree slope - south aspect (10° S)

The null hypotheses are:

1. Crop productivity is not a function of slope, position or aspect in the reclaimed landscape. If rejected, quantify the effect of slope, position and aspect.
2. Downslope salt transport is independent of slope and aspect. If rejected, quantify effect of slope and aspect.

Crop productivity and chemical properties are compared at upper, mid and lower slope positions. Soil sampling was done at two locations per plot at 5 depth intervals. Yields were measured on a 3 m x 13 m central portion of each plot.

2.4.2 Statistical Analysis

Soil chemistry and five-year yield data were analyzed as a split-plot in time design, with treatment and position as the main factors and year as the sub-plot factor. The ANOVA table for the crop and soil analysis is presented in Table 40. Treatment effects were decomposed into planned slope, aspect and slope x aspect contrasts. The main effect of position was broken down into planned linear and quadratic contrasts, as was year. All post hoc tests were conducted using Tukey's HSD.

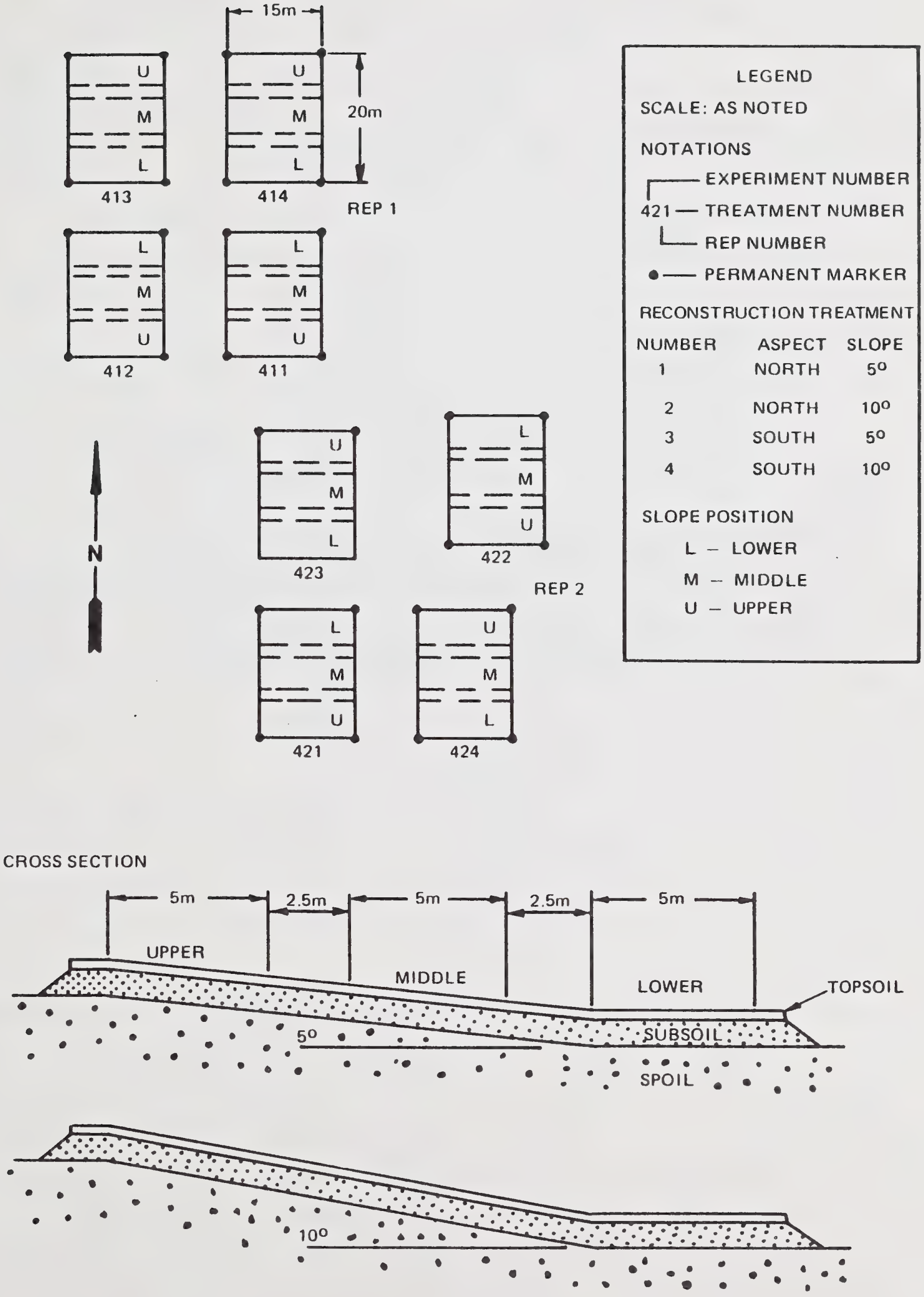


Figure 22. Plot layout, Slope Drainage Experiment.

Table 40. ANOVA table for crop and soil analyses, Slope Drainage Experiment.

Factor	Degrees of Freedom		Appropriate Error
Whole Plot			
Treatment (T)	3		TR
slope contrast		(1)	
aspect contrast		(1)	
slope aspect		(2)	
Position (P)	2		PR
linear contrast		(1)	
quadratic contrast		(1)	
TP	6		TPR
TR	6[a]		
PR	4[a]		
TPR	12[a]		
Split Plot			
Year (Y)	4		YR
linear contrast		(1)	
quadratic contrast		(1)	
TY	12		TYR
YP	8		YPR
TYP	24		TYPR
YR	8[a]		
TYR	24[a]		
PRY	16[a]		
TYPR	48[a]		
Replicate (R)	2		S(TYPR)
S(TYPR)	180		

[a] Error

For lower subsoil and spoil the chemical analyses were conducted over the 1984 to 1986 data due to missing data in the previous years.

2.4.3 Slope Drainage Yields

Forage yields on a dry weight basis were measured on first cuts made each July, 1982 to 1986. Note that the forage crop was established in 1981 and it differs in composition from those of other experiments.

Year and position were found to be significant. In 1985 and 1986 the highest and lowest yields, respectively, were reported while in other years they were intermediate. Yields increased downslope, and this was attributed to increasing moisture supply. Details are summarized below:

Year	1982	1983	1984	1985	1986
kg/ha	1841b	1859b	1750b	2618c	746a

n = 24, s.e. = 85.4, critical value = 350.

Position - the planned comparison indicates a significant linear increase in yield downslope, even though Tukey's HSD indicates no significant difference among positions.

Position	Upper	Middle	Lower
kg/ha	1650a	1823a	1859a

n = 40, s.e. = 57, c.v. = 228.

2.4.4 Slope Drainage Soil Salinity Analysis

Statistically significant findings for this experiment included year, position and treatment effects and as in other experiments, major differences occurred in the uppermost soil layers (Table 41).

2.4.4.1 Topsoil. Measured properties all changed, mainly in response to time and slope position (Table 42). Saturation percentages increased downslope and decreased over time. The interactions were such that there was a greater decline in the lower slope position over time so that in 1984 and subsequently all values were similar. EC and Na levels followed similar patterns: lower positions had greatest values while upper slopes had only slightly greater values than midslopes. Topsoil EC, Na and SAR all declined linearly with time across all treatments and positions. Interactions between

Table 41. Statistical summary for Slope Drainage Experiment, salinity data, 1982 to 1986.

Layer Parameter	Tmt	Position	Tmt x Position	Yr	Yr x Tmt	Yr x Position	Overall
Topsoil							
Sat %		*				*	
EC	*	*		*		*	
Na		*		*		*	
SAR				*			
Upper Subsoil							
Sat %				*	*		
EC				*	*		
Na				*			
SAR				*			
Lower Subsoil							
Sat %		*		*		*	
EC				*			
Na							
SAR		*				*	
Upper Spoil							
Sat %				*			
EC				*			
Na				*			
SAR				*			
Lower Subsoil - Upper Subsoil							
Sat %	*	*				*	*
EC							*
Na				*			*
SAR	*					*	*
Spoil - Lower Subsoil							
Sat %				*		*	*
EC							*
Na		*		*			*
SAR		*		*		*	*

Significant at p = 0.05

Table 42. Topsoil salinity, Slope Drainage Experiment, 1982 to 1986.

Saturation %

Position - the linear increase from upper to lower slope and the curvature are significant.

Position	Upper	Middle	Lower
Sat %	35	34	38

n = 80.

Year x Position - values for the lower slope position are higher in 1982 but decrease more in time than those for other positions.

Position	1982	1983	1984	1985	1986
Upper	41bc	32a	35ab	34a	34a
Middle	38ab	33a	33a	34a	34a
Lower	45c	41bc	35ab	35ab	35ab

n = 16, s.e. = 1.26, c.v. = 6.4.

Year - The linear decrease in time is significant with nearly all the change occurring in the first two years.

Year	1982	1983	1984	1985	1986
Sat %	41	36	34	34	35

n = 48.

EC (mS/cm)

Position - both the linear and quadratic contrasts with position are significant.

Position	Upper	Middle	Lower
EC	1.4	1.2	2.5

n = 80.

Year - the linear decrease with time is significant.

Year	1982	1983	1984	1985	1986
EC	2.4	1.8	1.8	1.3	1.2

n = 48.

Year x Position - the linear decrease with time is greater for the lower position than for others.

Year	1982	1983	1984	1985	1986
Upper	1.9cd	1.0a	1.8bc	0.9a	1.3ab
Middle	1.5bc	1.1ab	1.4b	1.2ab	0.9a
Lower	3.8f	3.1e	2.2d	1.8bc	1.5bc

n = 16, s.e. = 0.09, c.v. = 0.44.

Slope - the planned comparison for slope is also significant.

Slope	5	10
EC	1.4	2.0

n = 120.

(Continued...)

Table 42. Topsoil salinity, Slope Drainage Experiment, 1982 to 1986 (Concluded).

Na (me/L)

Position - quadratic and linear contrasts are significant.

Position	Upper	Middle	Lower
Na	8.0	7.1	16

n = 80.

Year - the linear decrease with time is significant.

Year	1982	1983	1984	1985	1986
Na	15	11	12	7.6	5.6

n = 48.

Year x Position - the decline with time is greatest for the lower slope position.

Year	1982	1983	1984	1985	1986
Upper	12ab	4.8a	11ab	6.1a	5.9a
Middle	8.6a	6.5a	8.9a	7.0a	4.7a
Lower	25c	21bc	15abc	9.8a	6.3a

n = 16, s.e. = 2.22, c.v. = 10.8.

SAR

Year - the linear decline with time is significant.

Year	1982	1983	1984	1985	1986
SAR	5.1	4.3	4.8	4.1	2.9

n = 48.

year and position, however, indicated lowest positions had greatest salt and Na concentrations in 1982 and while these declined considerably, they still remained slightly more concentrated in 1986 than upper and middle positions. Since 1985 all topsoils were rated Good, an improvement from their initial Fair rating.

2.4.4.2 Upper subsoil. Measured characteristics changed, primarily expressed as year by treatment interactions (Table 43). The general trend was for saturation percentage to decline initially then level off and this was most pronounced in Treatment 3 (5° S). EC across all treatments increased initially then declined slightly. EC, Na and SAR levels showed significant year by treatment differences, mainly in the last two years. Treatments 2 and 3 (10° N and 5° S) had higher values in 1985 and 1986 than the other treatments (Figures 23 to 25).

Upper subsoil quality in 1986 was Unsuitable in Treatments 2 and 3 due to high SAR and Poor in Treatments 1 and 4, limited by SAR and EC. At the beginning, Treatment 4 was Poor and Treatment 1 was Unsuitable because of high SAR.

2.4.4.3 Lower subsoil. Statistical analyses were done for 1984 to 1986 and indicated that saturation percentage, EC and SAR all changed over time, and that saturation percentage and SAR also exhibited position effects (Table 44). Saturation percentage decreased with time and increased downslope due to differences in the lower position. EC increased with time. SAR increased downslope due to differences between the lower slope and other positions. Also significant is that this trend was evident in 1984 but disappeared by 1986.

Lower subsoil quality was always Unsuitable due to excessive SAR (about 15).

2.4.4.4 Upper spoil. Analyses of 1984 to 1986 data indicated quadratic contrasts for saturation percentage, EC and Na levels and a linear decrease with time for SAR (Table 45). Saturation percentage peaked in 1985 whereas EC and Na levels were lowest in the same year.

Table 43. Upper subsoil salinity, Slope Drainage Experiment, 1982 to 1986.

Saturation %

Year - the linear decline with time is significant.

Year	1982	1983	1984	1985	1986
Sat %	52b	44a	41a	40a	40a

n = 48, s.e. = 1.27, c.v. = 5.3.

Year x Treatment - Treatment 3 declines more, especially after year 1, than others.

Year		1982	1983	1984	1985	1986
Treatment 1	5° N	48ab	44ab	43ab	39a	40a
Treatment 2	10° N	49ab	46ab	40a	44ab	42a
Treatment 3	5° S	62b	41a	42a	44ab	43ab
Treatment 4	10° S	49ab	44ab	40a	36a	37a

n = 12, s.e. = 3.42, c.v. = 19.1.

EC (mS/cm)

Year - the quadratic contrast is significant.

Year	1982	1983	1984	1985	1986
EC	6.1	6.9	7.7	6.8	6.9

n = 48.

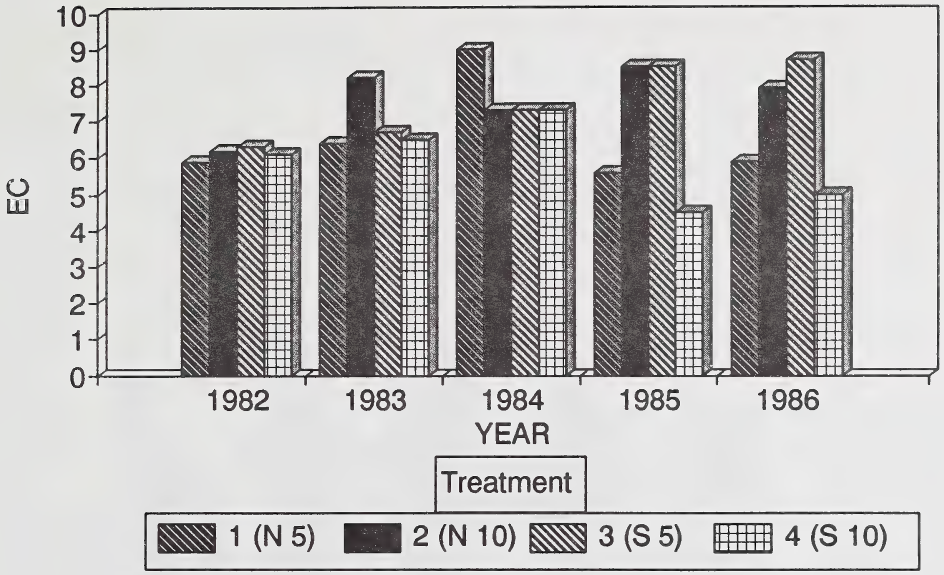
Year x Treatment - the slope x aspect interaction is large in the last two years, see Figure 23.

Na (me/L)

Year x Treatment, see Figure 24.

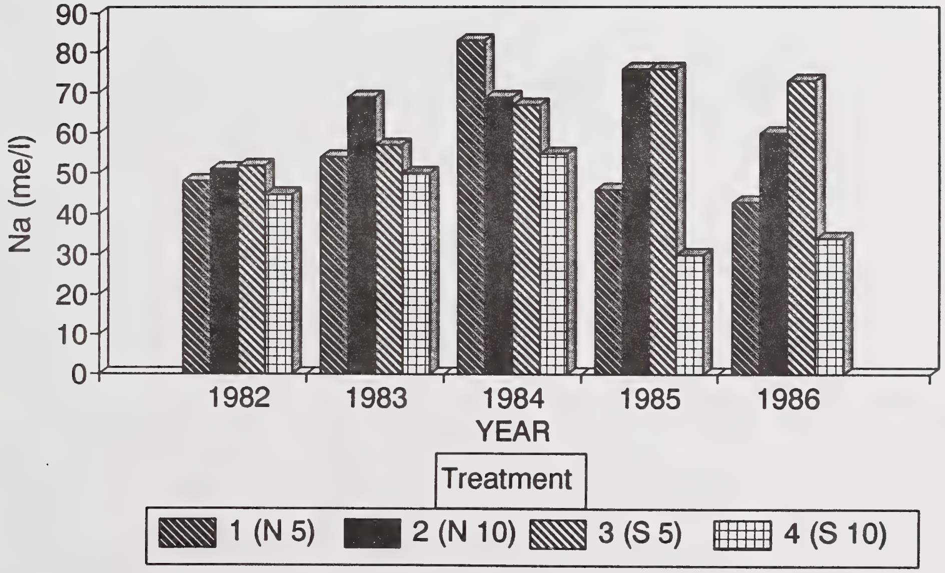
SAR

Year x Treatment, see Figure 25.



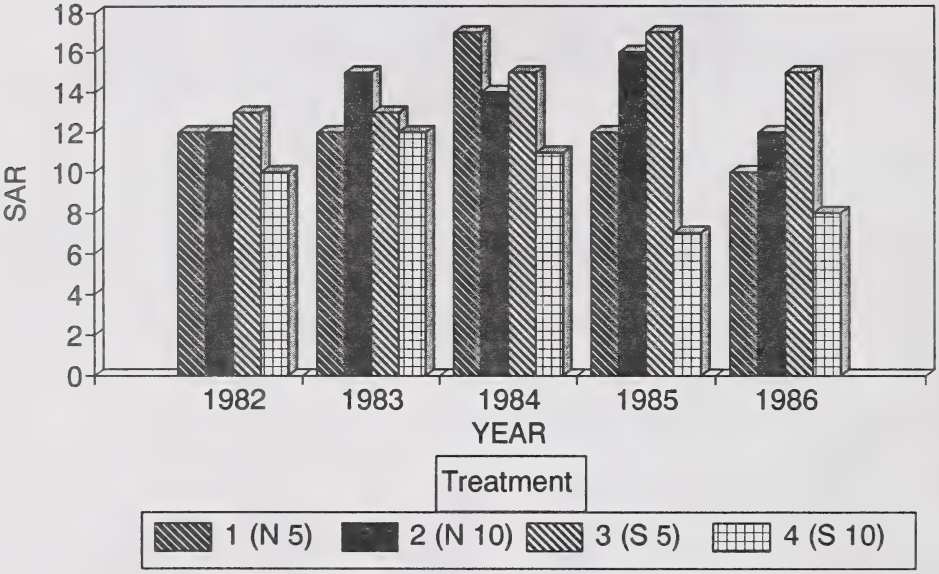
n = 12, s.e. = 0.625, c.v. = 3.3.

Figure 23. Upper subsoil EC by year and treatment, Slope Drainage Experiment, 1982 to 1986.



n = 12, s.e. - 7.18, c.v. - 38.2.

Figure 24. Upper subsoil Na by year and treatment, Slope Drainage Experiment, 1982 to 1986.



n = 12, s.e. = 1.32, c.v. = 7.0.

Figure 25. Upper subsoil SAR by year and treatment, Slope Drainage Experiment, 1982 to 1986.

Table 44. Lower subsoil salinity, Slope Drainage Experiment, 1984 to 1986.

Saturation %

Position - increasing Sat % downslope, significant linear contrast.

Position	Upper	Middle	Lower
Sat %	45	44	52

n = 48.

Year - decreasing Sat % with time.

Year	1984	1985	1986
Sat %	49	46	46

n = 48.

Year x Position - lower slope has a higher value in 1984 but approaches others in the last two years.

Year	1984	1985	1986
Upper	44a	44a	46a
Middle	44a	44a	44a
Lower	59b	49a	48a

n = 16, s.e. = 0.86, c.v. = 5.4.

EC (mS/cm)

Year - linear increase with time is significant.

Year	1984	1985	1986
EC	8.3	8.2	9.5

n = 48.

Na (me/L)

No significant factors.

SAR

Position - the linear increase downslope is significant although it is the comparison of the lower slope vs others that is important.

Position	Upper	Middle	Lower
SAR	15	15	19

n = 48.

Year x Position - there is a decline in SAR in the lower slope over time.

Year	1984	1985	1986
Upper	15a	15a	15a
Middle	15a	15a	15a
Lower	21b	18ab	16a

n = 16, s.e. = 0.72, c.v. = 3.5.

Table 45. Upper spoil salinity, Slope Drainage Experiment, 1984 to 1986.

Saturation %

Year - the quadratic contrast is significant.

Year	1984	1985	1986
Sat %	143	151	143

n = 48.

EC (mS/cm)

Year - the quadratic contrast is significant.

Year	1984	1985	1986
EC	5.8	4.8	6.3

n = 48.

Na (me/L)

Year - the quadratic contrast, indicating a decline in 1985 then an increase in 1986, is significant.

Year	1984	1985	1986
Na	67	49	58

n = 48.

SAR

Year - linear decrease with time.

Year	1984	1985	1986
SAR	35	30	28

n = 48.

Spoil quality was Unsuitable throughout due to extreme SAR (about 30).

2.4.4.5 Lower subsoil minus upper subsoil. Differences were significant in all parameters measured (Table 46). Saturation percentage and SAR differences were greater in Treatments 1 and 4 than 2 and 3, and greater in lower slopes than others but primarily in 1984. Overall, upper subsoil had lower saturation percentage EC, Na, and SAR than lower subsoil.

Na differences increased from 1984 to 1986 suggesting improvement in the upper subsoil, degradation in the lower subsoil,or both.

2.4.4.6 Spoil minus lower subsoil. Differences from 1984 to 1986 were as expected in reflecting main properties of the two materials but there also were some time and position effects (Table 47). Saturation percentage peaked in 1985, primarily due to differences in the lower position. Na differences increased (negatively) from upper to lower slopes and with time, indicating that lower subsoil is deteriorating relative to spoil. SAR differences decreased downslope and with time. Both lower subsoil and spoil had declining SAR levels but spoil SAR was decreasing more rapidly.

2.4.5 Soil Moisture

Soil moisture percentage was measured monthly through the growing season, by neutron probe. Major factors considered in gathering and interpreting moisture data included:

1. moisture availability to plants and depth of rooting;
2. occurrence of saturated conditions, or perched water table;
3. differences between slope angle and aspect;
4. effects of moisture and crops on soil development.

As an aid to interpreting moisture measurements, special studies on moisture availability were conducted in 1987 and results are shown in Table 48. Driest moisture levels recorded were: topsoils 12%, subsoils 16%, and spoils 26%. Topsoil values match wilting point; subsoil values are about 4% below those measured in the lab; and spoil values are 6% higher.

Table 46. Lower subsoil (SS2) minus upper subsoil (SS1) salinity, Slope Drainage Experiment, 1984 to 1986.

Saturation %

Treatment - the slope by aspect interaction is significant.

Treatment	5° N	10° N	5° S	10° S
SS2-SS1 Sat%	9.7b	3.4a	2.3a	9.3b

n = 36.

Position - there is a significant linear increase downslope.

Position	Upper	Middle	Lower
SS2-SS1 Sat %	4.5	4	9.6

n = 48.

Year x Position - 1984 lower position has a bigger difference than all others.

Year	1984	1985	1986
Upper	2.7a	4.5a	6.2a
Middle	2.2a	5.3a	4.4a
Lower	16b	6.7a	6.2a

n = 16, s.e. = 1.01, c.v. = 7.7.

Overall Difference: n = 144, SS2 (47) - SS1 (40.8) = 6.2.

EC (mS/cm)

Overall Difference: n = 144, SS2 (8.7) - SS1 (7.1) = 1.6

Na (me/L)

Year - the linear increase in the difference with time is significant.

Year	1984	1985	1986
Na	7.3	15.6	24.8

n = 48, Overall Difference: n = 144, SS2 (75) - SS1 (59) = 16

SAR

Treatment	5° N	10° N	5° S	10° S
SAR	4.1b	2.9a	1.8a	5.6b

n = 36.

Year x Position

Year	1984	1985	1986
Upper	3.0abc	0.8ab	4.5bc
Middle	-1.2a	3.7abc	3.6bc
Lower	7.1c	5.2bc	3.9bc

n = 16, s.e. = 1.016, c.v. = 5.04.

Overall Difference: n = 144, SS2 (16.3) - SS1 (13) = 3.3

Table 47. Spoil (Sp) minus lower subsoil (SS2) salinity, Slope Drainage Experiment, 1984 to 1986.

Saturation %

Year - quadratic contrast is significant.

Year	1984	1985	1986
Sp-SS2 Sat %	94	105	97

Year x Position

Position	1984	1985	1986
Upper	95ab	104bc	95ab
Middle	100abc	99abc	99abc
Lower	86a	113c	95ab

n = 16, s.e. = 3.6, c.v. = 17.3.

Overall Difference: n = 16, Sp (146) - SS2 (47) = 99.

EC (mS/cm)

Overall Difference: n = 144, Sp (5.6) - SS2 (8.7) = -3.1.

Na (me/L)

Position - the linear increase in the magnitude of the difference is significant.

Position	Upper	Middle	Lower
Sp-SS2 Na	-8.3	-14	-28

n = 48.

Year - linear contrast is significant.

Year	1984	1985	1986
Sp-SS2 Na	-9.1	-22	-20

n = 48.

Overall Difference: n = 144, Sp (58) - SS2 (75) = -17.

(Continued...)

Table 47. Spoil (Sp) minus lower subsoil (SS2) salinity, Slope Drainage Experiment, 1984 to 1986 (Concluded).

SAR

Position - linear decline downslope is significant.

Position	Upper	Middle	Lower
Sp-SS2 SAR	17	15	12

n = 48.

Year - linear decline in the difference with time is significant.

Year	1984	1985	1986
Sp-SS2 SAR	18	14	12

n = 48.

Year x Position

Year	1984	1985	1986
Upper	20c	16b	14ab
Middle	20c	14ab	12a
Lower	13ab	13ab	11a

n = 16, s.e. = 0.607, c.v. = 3.8.

Overall Difference: n = 144, Sp (31) - SS2 (16) = 15.

Table 48. Moisture availability, Slope Drainage Experiment.

	Bulk Density (g/cm^3)	Wilting Point (Wt.%)	Wilting Point (Vol.%)	Field Capacity (Wt.%)	Field Capacity (Vol.%)	Availability (Vol.%)
Topsoil[a]	1.3	9	12	18	24	12
Subsoil[b]	1.7	12	20	23	39	19
Spoil[c]			20		39	19

[a] Based on mean of 15 samples

[b] Based on mean of 30 samples

[c] Treated as equivalent to subsoil

Soil moisture classes were developed, indicating droughty (wilting point plus 5%) and readily available (remaining available moisture) soil moisture levels for crop growth. The percentage of months with adequate moisture content was then determined from field data, and is shown in Table 49.

In topsoils and subsoils, upper slope positions had least available moisture, lower slope positions had most available water. Spoils were very moist in all cases, but there is no evidence of a water table. South aspects were slightly drier than north.

2.4.6 Bulk Density

Selected bulk density data are given in Table 50. Specific results were chosen so as to exclude possible composite readings in the vicinity of material interfaces.

Topsoil bulk densities in 1987 averaged 1.34 g/cm^3. Differences among treatments and positions were not significant; however, the 1983 values are considerably higher than subsequent values, differing by around 0.30 g/cm^3.

Upper subsoils (15 to 30 cm layer), varied considerably in bulk density from around 1.1 to 1.9 g/cm^3 and averaged 1.59 g/cm^3 from 1985 to 1987, after declining from 1.75 g/cm^3 in 1983. As for topsoils, there are no differences among treatments or positions, but the decline after 1983 is important. A question remains regarding reliability and accuracy of the measurements.

Measurements of lower subsoil densities indicated that values range from 1.74 to 1.85 g/cm^3 and averaged 1.81 g/cm^3, in 1987. While there are slight differences among treatments and positions, these are technically minor and they are not significant. Changes over time are also minor and may be due to calibration differences. Spoil bulk densities were considerably lower, ranging from a low of 1.41 g/cm^3 in 1985 to a high of 1.61 g/cm^3, in 1987. Differences between treatments or positions are minor.

Table 49. Percentage of months with moisture content readily available to plants[a], May to September, Slope Drainage Experiment, 1982 to 1986.

Treatment	Material[b]	Depth	Upper	Middle	Lower
1	TS	0 to 15	40%	47%	53%
	SS	15 to 30	13	40	60
(5° N)	SS	40 to 55	20	53	100
	SS[c]	55 to 70	40	100	100
	SP	170 to 185	100	100	93
2	TS	0 to 15	47	53	40
	SS	15 to 30	20	27	40
(10° N)	SS	40 to 55	7	7	93
	SS[c]	55 to 70	7	27	100
	SP	170 to 185	100	100	100
3	TS	0 to 15	27	33	47
	SS	15 to 30	7	7	27
(5° S)	SS	40 to 55	13	0	53
	SS[c]	55 to 70	13	20	100
	SP	170 to 185	100	93	33
4	TS	0 to 15	20	40	40
	SS	15 to 30	7	20	40
(10° S)	SS	40 to 55	0	0	93
	SP[c]	55 to 70	13	60	100
	SP	170 to 185	100	100	100

[a] TS = greater than 14% moisture, SS and SP = greater than 17% moisture (see Table 48).

[b] TS=Topsoil, SS=Subsoil, SP=Spoil [c] possible composite of materials

Table 50. Selected bulk density values (g/cm^3), Slope Drainage Experiment.

Material	1983	1985	1986	1987
1. Topsoil n = 16	1.64	1.28	1.29	1.34
2. Upper Subsoil n = 16	1.75	1.59	1.59	1.58
3. Lower Subsoil n = 16	1.85	1.74	1.75	1.81
4. Lower Spoil n = 16	1.56	1.41	1.47	1.61

2.4.7 Root Distribution

In all treatments and the three slope positions, there were abundant fine and very fine roots in the topsoils and upper subsoils, that is, 0 to 30 cm. Roots were plentiful to about 60 cm grading to few below. In upper and middle positions, roots penetrated to about 145 cm whereas in lower positions they terminated at about 100 cm. The shallower rooting in the lower positions is attributed to the shallower occurrence of spoil.

3. SYNTHESIS

This section provides interpretations and discussions on the importance of the statistical findings in terms of soil quality and development, relationship to findings in the literature and limitations of the data. Each experiment is addressed separately considering, in order, crop yields, soil salinity, soil moisture, bulk density, and root distribution. Finally, comparisons among experiments are made and unique features or problems are noted.

3.1 SUBSOIL DEPTH EXPERIMENT

3.1.1 Crop Yields

3.1.1.1 Forage. Yields showed two statistically significant trends: yields declined with time; and yields increased with increased subsoil thickness. The time relationship reflects an aging forage stand or declining seasonal rainfall and soil moisture reserves, or most likely a combination of these factors. Rainfall during the early part of the growing season seems to have been a major controlling factor as indicated by the evaluation of rainfall data versus yields shown in Table 51.

The clear relationship between increasing yield and increasing subsoil thickness is considered to reflect increasing moisture storage and supply in the root zone exploited by the crop. Differences in soil chemical or physical properties among treatments are too small to account for the yield pattern. High bulk densities, along with moderate salinity and sodicity probably depress yields uniformly across all treatments.

Forage yields on undisturbed control plots from a few Solonetzic soil study sites in Paintearth and Flagstaff counties and regional farm yields were examined and compared with the average reclamation plot forage yields for four years and are also given in Table 51.

Table 51. Rainfall distribution and yield data, Subsoil Depth Experiment and comparative forage yields.

Year	Rainfall (mm) May	Rainfall (mm) May 1 to July 15	Distribution	All Treatments Mean Yield kg/ha	Comments
1983	41	316	127 mm late June	2676	highest total rainfall > 40 mm/mth, 1st year crop
1984	15	100	62 mm mid-June	2515	dry May and July
1985	45	113.5	35 mm per month	2840	good monthly distribution
1986	12	118	71 mm Jul 7 to 13	2263	dry May, 60% of rain just before harvest
Mean				2573	

Year	Undisturbed Control[a]	3 Layer Plow[a]	Regional[b]	Torlea Paintearth[c]
1983	1682 (1)[d]	2959 (1)	3360	1117
1984	1457 (1)	1726 (1)	2912	676
1985	1525 (2)	2915 (1)	2688	2242
1986	1535 (3)	2309 (2)	3808	1456
Mean	1550	2477	3192	1373

---

[a] Yields from Solonetzic Soils deep plowing, ripping and liming feasibility studies, Flagstaff and Paintearth Counties, Alberta Agriculture. (Yields are from strips on farm fields).

[b] Agricultural Reporting Area 4A data, Alberta Agriculture. (Farmers reported yields).

[c] Paintearth Mine Torlea Soil Reclamation Trials. Reference yields (reseeded natural Torlea soil).

[d] Number of reporting trials.

Mean forage yields over four years are given below:

Treatment	1	2	3	4	5	6
Subsoil Depth (cm)	0	25	65	135	165	335
kg/ha	2219	2150	2448	2807	2910	3484

Forage yields on all treatments are considerably higher than the undisturbed yields on Solonetzic study sites and Treatment 6 yield is double. Yields on Solonetzic soil study plots treated with 3-layer (deep) plowing are somewhat higher and close to yields on Treatments 1 to 4. Since the 3-layer plow breaks up and inverts B and C horizons while leaving A horizons intact, its effect on Solonetzic soils may be similar to the mined situation where subsoil materials are replaced over spoil, and capped with topsoil. Regional yields on undisturbed agricultural lands covering Solonetzic and Chernozemic soils should be higher than those on Solonetzic soils and are closest to Treatment 5 yields.

There are serious limitations in comparing the experimental yields with other yields:

1. sample number is very small in the Solonetzic Soil Study, allowing large variation due to management practices such as seedbed preparation, fertilization, etc.;
2. crop composition is not specified, for example, alfalfa versus grasses or other legumes;
3. the regional yields represent a wide undefined range of soil types; and
4. summer rainfall is extremely variable in this region generally occurring as spotty showers, thus, comparisons among sites may be unreliable due to rainfall effects.

From a statistical and scientific perspective, these yield comparisons are invalid and a sound minimum depth of subsoil based on yield cannot be recommended.

Comparable findings in North Dakota (Doll et al. 1984) showed that highest forage yields occurred on reclaimed soils with 20 cm of topsoil over 70 to 90 cm of subsoil. Increasing topsoil thickness to 60 cm did not contribute to significantly higher yields. Yields of alfalfa, crested wheatgrass and native grass were monitored from 1976 to 1979.

3.1.1.2 Cereal. Grain yields were generally very poor and this is attributed mainly to low rainfall and restricted rooting depth (due to subsoil compaction). Nevertheless, significant treatment differences occurred. Treatment 1 (no subsoil) was significantly lower yielding than Treatments 3 and 4 (65 and 135 cm of subsoil). Yields on other treatments were intermediate.

Grain yields also differed from year to year, being highest in 1982 and 1985, and lowest in 1983. While low and poor distribution of rainfall are thought to be the primary cause of low and varying yields, the relationship is not as clearly defined as for forages.

Mean grain yields over five years are compared to Solonetzic soil study site controls and farm yields below:

Treatment Subsoil Thickness (cm)	1[a] 0	2[a] 25	3[a] 65	4[a] 135	5[a] 165	6[a] 335	U[b]	ARA4A[c]
(kg/ha)	785	928	963	973	869	844	1293	2132

Year	1982	1983	1984	1985	1986	Mean
SS[a] kg/ha	1249	407	743	1203	853	891
U[b] kg/ha	2117	1313	1039	1280	2030	1556

[a] Subsoil Depth Experiment, (by treatment n = 15; by year n = 18)
[b] Controls on Solonetzic soil study sites
[c] Agricultural Reporting Area No. 4A

All treatments are well below the undisturbed yields, varying from 60% to about 70% of the undisturbed values and only 40% of regional average yields. By year, only 1985 yields approached undisturbed values. Because of the very low yields and harmful effects of subsoil compaction, it is recommended that cereal yields not be used as a criteria in determining subsoil depth.

Results from North Dakota (Doll et al. 1984) showed that spring wheat yields (1975 and 1978) were highest on subsoil depths of 90 to 120 cm, and that yields were within 10% on subsoil depths of 50 to 80 cm. Current findings in that highest yields were on Treatments 3 (65 cm subsoil) and 4 (135 cm subsoil) are within the optimum range found in North Dakota.

3.1.2 Salinity and Sodicity

3.1.2.1 Soil layers. Topsoils under both crops and across all treatments improved from Fair to Good during the first three years and have since stabilized. EC and SAR were both initially limiting although EC was more critical. Saturation percentage and Na levels also decreased with time. Topsoils took longer to improve under cereals than under forages.

Upper subsoils changed significantly with time but there were no treatment or crop effects. Saturation percentage decreased in the first two years then stabilized; EC increased with time; and Na and SAR both increased then decreased. Subsoil quality was Poor throughout, due to excessive EC and SAR. The change in saturation percentage causes problems in interpretation of EC and Na levels. It is likely that yearly average saturation percentage, which is based on lab technician judgement, reflects lab rather than soil differences. If corrections are applied to make all saturation percentages across years identical then the EC and Na levels change as follows:

	1982	1983	1984	1985	1986
Lab Results[a]					
Sat %	45	42	38	38	39
EC (mS/cm)	5.3	5.4	6.2	6.1	5.9
Na (me/L)	37	39	48	39	37
Adjusted Values[b]					
Sat %	38	38	38	38	38
EC mS/cm	6.3	5.9	6.2	6.1	6.0
Na (me/L)	44	43	48	39	38

[a] Means of all treatments (n = 60)

[b] Calculation procedure: $\frac{\text{Lab Sat \%}}{\text{Adjusted Sat \%}}$ x Lab EC = Adjusted EC

When adjustments to the means are applied, it becomes evident that EC does not increase with time. There is also a shift in Na and SAR levels such that recent decreases exceed initial increases. The result is a strong trend toward upper subsoil improvement which should continue and, if so, the soil quality could then be upgraded to Fair.

Lower subsoil changed with time. There were treatment effects but only with respect to saturation percentage. EC, Na and SAR levels all increased with time but started to decrease in the last 1 or 2 years. Final levels remain greater than initial levels. Lower subsoil quality is Poor in terms of EC but has degraded to Unsuitable in terms of SAR. In examining intermediate subsoil layers (Table 52), it is evident that they remain Poor and only the subsoil above spoil is Unsuitable due to SAR.

Spoil was statistically analyzed for the last 3 years only. Results indicate that EC, Na and SAR increased from 1984 to 1985 then decreased in 1986. Differences in the last three years are minor and meaningless in practical terms. Excessive SAR levels render the materials Unsuitable. The most important change however, was the increase in EC from about 4 mS/cm in 1982, to 6 mS/cm in 1983 and 1984, and to over 7 mS/cm in 1985 and 1986. The increased salinity is attributed to leaching of salts from the subsoil.

If lab results of EC for all layers are added (i.e. cumulative salinity per profile) for 1982 and 1986 it would appear that total salts have increased. But if saturation percentages and EC values are adjusted, then there is almost no change in the total salts within the profile (Table 53). Thus, with adjustments, it is clear that salt translocation occurred within the Treatment 5 profile and there may have been some leaching through the profile in the forage plots. If adjustments are not made, there is an increase in profile salinity suggesting upward movement from the spoil.

Differences between lower and upper subsoil did not change with time, treatment, or crop. However, overall it is clear that lower subsoils are inferior to upper subsoils in terms of saturation percentage, EC, Na and SAR. If adjustments for saturation percentage are made, salinity and sodicity differences become more pronounced.

Table 52. Soil chemical properties, Treatment 5 (165 cm subsoil), Forage, Subsoil Depth Experiment, 1986.

Depth	pH	EC	SAR	Ca	Mg	Na	K	SO_4	Cl	Sat%	Rating
				me/L							
0 to 15[a]	7.2	2	2	13	5	5	0.6	11	0.8	35	G[c]
15 to 30	7.6	7	8	26	23	41	0.8	71	0.5	38	P
40 to 65	7.9	8	11	26	29	57	1.1	91	0.3	41	P
85 to 100	8.0	8	10	26	27	52	1.0	86	0.2	41	P
120 to 135	7.9	7	10	25	25	47	1.0	78	0.3	42	P
135 to 150	8.0	7	10	25	23	51	0.9	80	0.3	43	P
165 to 180[b]	8.0	8	12	26	23	62	1.0	95	0.4	42	U
180 to 195	8.1	8	29	12	8	69	0.8	72	0.5	109	U
225 to 245	8.2	7	36	8	4	65	0.7	62	0.5	149	U

[a] Topsoil/subsoil interface

[b] Subsoil/spoil interface

[c] G, Good; F, Fair; P, Poor; U, Unsuitable (Alberta Agriculture 1987)

All values are means of 6 samples.

Table 53. Comparison of adjusted and laboratory EC values (mS/cm), Treatment 5, Subsoil Depth Experiment, 1982 and 1986.

Depth (cm)	Material	Cereal				Forage			
		1982		1986		1982		1986	
		Adj EC	Lab EC	Adj EC	Lab EC	Adj EC	Lab EC	Adj EC	Lab EC
0 to 15	TS	3.2	2.6	1.6	1.6	4.1	3.3	2.1	1.9
15 to 30	SS	5.2	4.9	5.7	5.9	5.8	5.4	5.9	6.6
40 to 65	SS	6.4	5.9	7.1	7.3	6.5	5.8	7.9	8.1
85 to 100	SS	7.4	6.6	8.1	8.0	7.0	6.1	7.6	7.7
120 to 135	SS	8.4	7.4	8.5	7.6	8.0	6.9	7.3	7.3
135 to 150	SS	8.3	7.0	7.7	7.5	8.3	7.2	7.5	7.4
165 to 180	SS	8.0	6.9	8.5	8.1	11.2	8.9	8.4	8.3
180 to 195	SP	5.9	4.2	4.9	7.8	6.0	6.7	5.9	7.5
225 to 245	SP	5.9	4.2	6.2	7.9	5.7	4.1	7.3	6.9
		----	----	----	----	----	----	----	----
Total		58.7	49.7	58.3	61.7	63.6	53.5	59.9	61.7
Mean EC		6.5	5.5	6.5	6.8	7.0	5.9	6.6	6.8

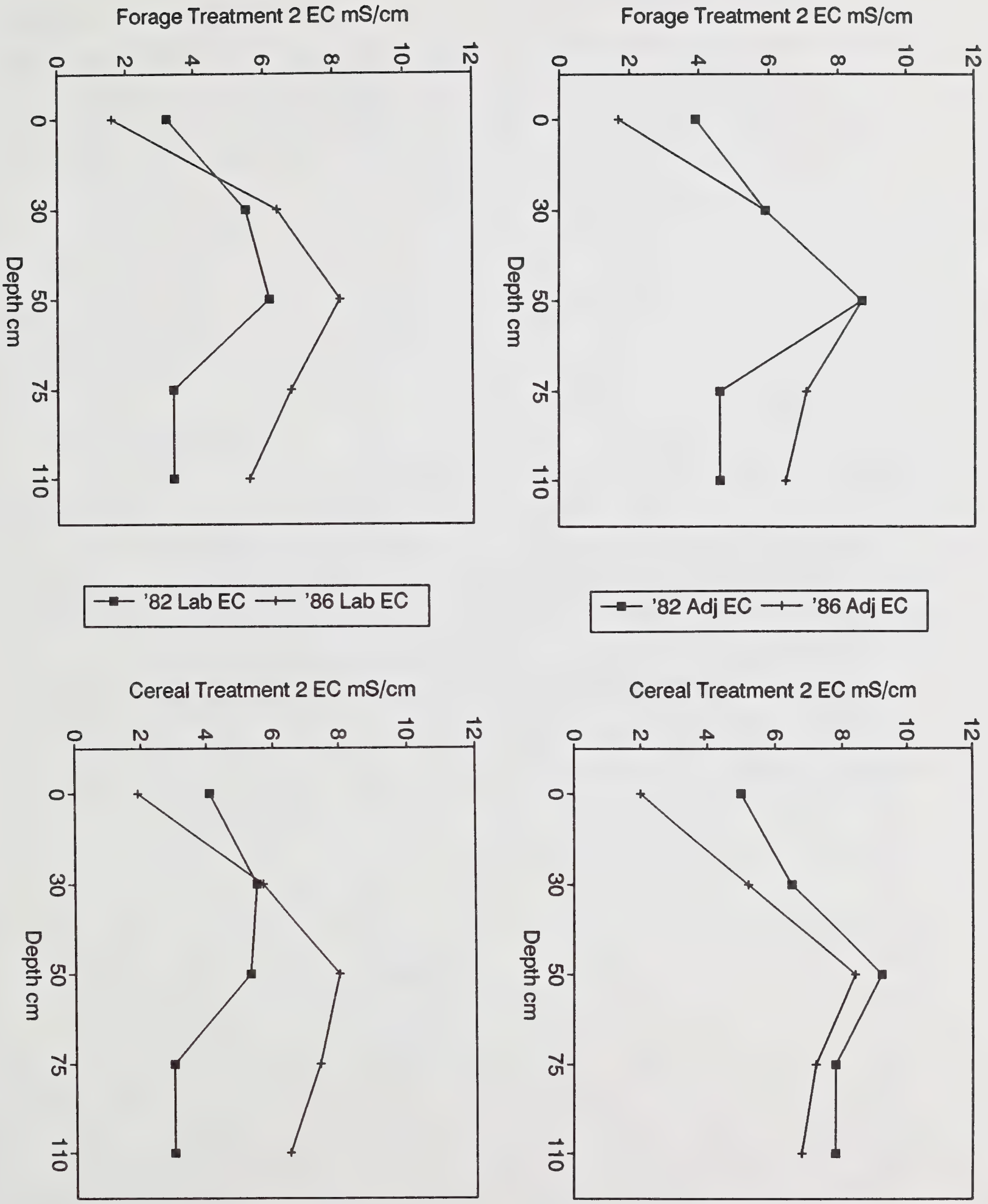
All values are means of 6 samples.
Standardized saturation percentages (wt. basis) for topsoil (TS) = 32%; subsoil (SS) = 42%; spoil (SP) = 140%.

Differences between spoil and lower subsoil indicated overall differences in all parameters between layers, reflecting known spoil and subsoil characteristics. Of interest are the treatment effects. The difference in EC and SAR between spoil and lower subsoil decreases with increasing thickness of subsoil. EC and Na levels in all spoils and lower subsoils have increased with time, but the spoil appears to have changed progressively less with increasing thicknesses of subsoil. Although changes within each layer are too small to date to be statistically significant, it is evident that there is more downward salt movement around the spoil interface in shallower than in deeper subsoils.

Literature, from North Dakota (Halvorson 1985, USDA 1979), indicates downward leaching of salts to some 40 cm below the spoil interface, or to depths of 60 to 90 cm.

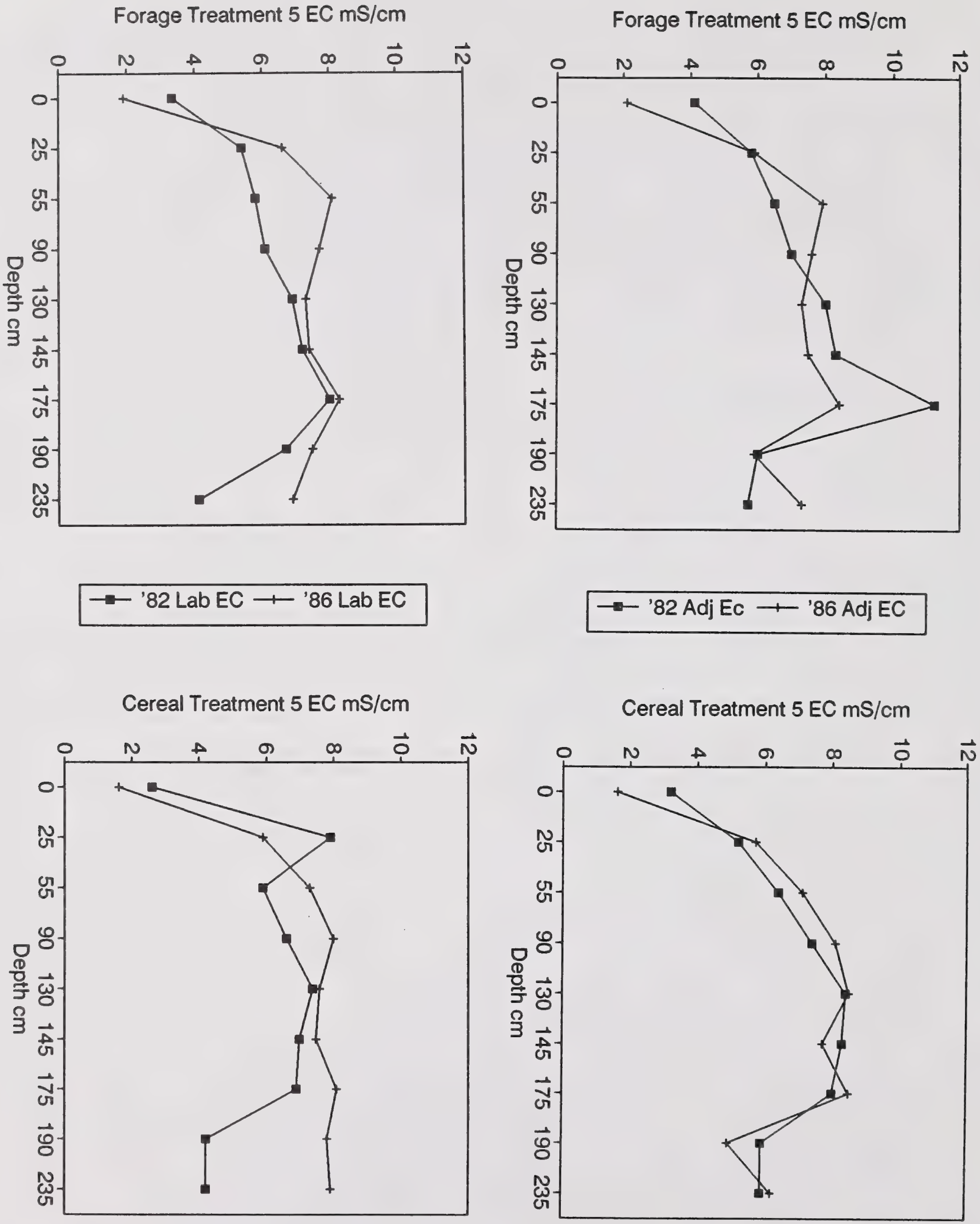
3.1.2.2 Treatments. Effects of treatments are generally lacking in the four primary soil layers. However, root zone quality is clearly related to subsoil thickness such that the deeper the spoil, the better the soil. Topsoils are now Good (EC and SAR) in all treatments. SAR, a key indicator, is generally Poor in the subsoil, grading to Unsuitable in the subsoil sample interval above the spoil and continuing so into the spoil. Subsoils and spoils are Poor in all treatments at all depths as expressed by EC. Therefore, in the root zone, Poor or better quality is governed by SAR, and is about 15 cm less in depth than the depth to spoil. If the root zone thickness (to spoil) exceeds a particular crop's rooting depth by 15 cm, then the depth to spoil may be considered adequate.

3.1.2.3. Special features. Leaching in the upper profile occurred. Topsoils improved while upper subsoils initially degraded, due to salts translocated from above, and then improved. A salt accumulation zone was developing in the lower subsoil in Treatments 2 and 3. In Treatments 4, 5 and 6, two recognizable accumulation zones are developing: one at 40 to 100 cm and one above and below the spoil interface. Figures 26 and 27 illustrate these patterns for forage plots of Treatments 2 and 5. Both adjusted and actual lab values are shown. Table 52 shows the complete soil analyses results for



n = 6

Figure 26. Salinity profiles for Treatment 2 (25 cm Subsoil), 1982 and 1986.



n = 6

Figure 27. Salinity profiles for Treatment 5 (165 cm Subsoil), 1982 and 1986.

Treatment 5 and also indicates these two salt accumulation layers reflected in relative increases in EC, SAR, Na, and SO_4. Examination of Mg, Na and SO_4 levels over time indicated leaching from topsoils and accumulation at 40 to 100 cm. Upper spoil increased in Ca, Mg, Na, and SO_4 concentrations which indicates leaching from above. A lack of shallow water tables or high moisture readings in spoil supports this leaching concept rather than capillary rise of salts. However, in lower subsoil, only Na and SO_4 increased and this suggests diffusion of Na_2SO_4 from spoil into subsoil. Perhaps leaching of all salts occurs by unsaturated flow through cracks whereas sodium salts rise by diffusion through the matrix.

3.1.3 Soil Moisture

Soil moisture data were summarized and they reflect four important factors:

1. Moisture availability: Soil moisture supply was inadequate about half the time in the upper 30 cm of cereal plots and it was inadequate less than 10% of the time below about 65 cm. Forage plots were much drier with moisture supply being inadequate more than half the time down to spoil or about 140 cm, whichever was shallower.
2. Water tables: Maximum soil moisture levels seldom exceeded field capacity and were always well below saturation percentage. There is no evidence that water tables were within monitoring depths.
3. Crop effects: Soils within cereal plots are characterized by better moisture supply than in forage plots. This reflects higher evapotranspiration, longer growing season and greater rooting depths of forages.
4. Soil development: One might expect soils under forages to have more cracking (higher frequency, wider, deeper) since they are considerably drier. This should allow greater infiltration and downward percolation, but a lack of crop effects in the statistical analysis of salinity and sodicity in the primary

soil layers indicates that, to date at least, crops have not had a significant impact on salt movement. While crops did not affect soils to date, based on parameters monitored, it is very important that on these soils forage yields were respectable but cereal yields were very poor.

3.1.4 Soil Bulk Density

Soil density information reveals several key findings:

1. Topsoils: Bulk density was variable but ranged from 1.2 to 1.4 g/cm^3 in the latter years which is comparable to agricultural soils in the region. There were no treatment or crop effects. There is an apparent decrease in density with time.
2. Subsoils: The entire subsoil layer in all treatments was compacted during plot construction and densities have remained variable but very high since, averaging > 1.7 g/cm^3. There is no evidence to support a change in the near future unless special efforts to ameliorate compaction are undertaken. Until 1987, there were no differences among treatments or between crops.
3. Spoils: Spoil bulk densities averaged 1.45 to 1.50 g/cm^3 and are considered to be in the normal range for parent materials. Spoil densities did not change during the monitoring period and there were no differences among treatments or crops.

Examination of densities of all layers over time indicates that topsoil and upper subsoil densities declined whereas lower subsoil and spoil densities remained steady. This is a favourable trend in the upper profiles but gravimetric samples taken in 1987 indicate relatively higher densities in the upper subsoil horizons. The only apparent reasons for this discrepancy are effects of access tube extensions and installation, and calibration or instrument error for the neutron probe readings. Digging around the access tube to install the extension tubes would have loosened the upper subsoil. When the soil was replaced and tamped, it likely was not packed as much.

Excessive compaction and high bulk density in the subsoil layer seriously hampered cereal crop growth and may have inhibited forage production. Densities exceeding 1.45 g/cm^3 to 1.55 g/cm^3 are known to reduce crop yields based on lab and field studies throughout North America (Bowen 1981, Can-Ag Enterprises 1988).

It was thought that deep rooting forages would help to reduce compaction in the subsoil; however, results to date do not support this. It is possible that the methods of measurement and variability mask slight changes that may have occurred. Regardless, densities remain very high and even if conditions are slowly improving it would still take many years to achieve significant improvement.

3.1.5 Root Distribution

The soil moisture profiles reflect root distribution such that the majority of cereal roots are confined to the upper 30 cm whereas forage roots are mainly above spoil or above 120 cm in deeper subsoil.

Rooting depth is governed by crop characteristics and the root zone environment; especially, moisture and nutrient supply, aeration, root penetration resistance and chemical toxicity. Topsoils are considered to be similar to those of undisturbed agricultural lands. There is no difficulty in preparing a good seed-bed and no crusting problems were experienced. In these reclaimed soils the main constraints to deeper rooting within the subsoil appear to be physical: high bulk density, low porosity and poor structure. Forage roots are predominantly "exped" ("exclod" is more appropriate) and frequently flattened as a result of being compressed between the clods. The lack of vertical continuity of pores or planar voids between clods as exists in a natural prismatic soil structure, in addition to the high bulk density, likely increases energy expended by plants to extend roots downward and probably restricts air exchange. Roots do not penetrate spoil more than about 15 cm and this may be due to chemical constraints (high SAR, high Na, low Ca, high pH), unavailability of moisture, as well as poor structure and poor aeration. Bulk densities of spoils are not excessive.

For cereal crops the constraints to deeper rooting appear to be insurmountable so roots are confined to the topsoil and upper subsoil. This limits moisture availability and makes good crop performance dependent on frequent rains. Extended drought periods could be and indeed have been devastating, even though soil moisture readings indicated that moisture was "available" below about 40 cm. The reclaimed subsoil, therefore, appears unsuitable to date for cereals. Subsoil depth differences are considered to be meaningless in this context.

3.1.6 Interactions

Forage roots penetrated much deeper into subsoils, in spite of the high densities and above normal salinity and sodicity. Forage yields were closely linked to total precipitation and soil moisture storage rather than to regularity of rains, the latter being critical for cereals. As previously noted, forage yields on reclaimed soils exceeded those on natural and subsoiled Solonetzic soils in the region. Besides possible management and climatic differences in comparing very few sites, a possible explanation for this is that forage roots were able to penetrate deeper and take advantage of greater soil moisture reserves in reclaimed soils with deep (> 1 m) subsoils than they do in undisturbed agricultural soils. In natural soils, the Ccasa horizon may act as a chemical barrier to root growth and also as a moisture barrier. The osmotic effects of salts in the salt accumulation layer, often at 40 to 70 cm in natural soils, may increase moisture tension enough to greatly reduce the plant's ability to uptake moisture and perhaps preclude deeper rooting. If this is so, then if and when the reclaimed soils develop a more pronounced salt accumulation layer forage rooting depth may also be reduced so that the linear relationship between deeper subsoil and higher yields would no longer apply. Rather, yields may level off at subsoil depths corresponding to the depth of salt accumulation. In shallow subsoil treatments, this may be at least 15 cm above the spoil: in deeper treatments it may be below 40 cm, but above 100 cm, based on 1986 salinity profiles.

3.2 TORLEA SOIL EXPERIMENT

3.2.1 Crop Yields

Forage yields on the Torlea Experiment were affected by treatment, amendment, and year.

No topsoil over spoil (Treatment 1) resulted in zero yields except with surface ash amendment in which case yields were very low. Topsoil placement over spoil resulted in substantially higher yields (Treatment 2). Yields increased further on treatments with topsoil over subsoil over spoil (Treatments 3 to 7). Subsoil horizon mixes and depths did not result in statistical yield differences but deeper subsoils tended to yield higher, and buried ash was detrimental.

Surface amendments proved to be very beneficial: ash out-yielded gypsum and control plots, however ash causes some problems with vehicle movement. Gypsum plot mean yields, 1983 to 1986, were almost significantly higher than control yields.

Yields declined with time, likely due to aging stands and to intensifying drought.

Year by amendment interactions indicated that in 1983, 1984 and 1986 ash plot yields were highest, followed in order by gypsum and control but in 1985 ash plot yields were lowest. The low yields on the ash plots were attributed to serious gopher damage that spring. Crops rebounded in 1986 after the gopher problem was eliminated.

Comparing forage yields to yields on controls and 3-layer plow treatments on Solonetzic soil study sites (see Tables 5 and 22) indicates yields on all but Treatment 1 were well above undisturbed values. Treatments 3 to 7 yielded much better than 3-layer plow plots and better than regional farm yields. However, as mentioned previously these yields from other studies are not scientifically valid comparables.

3.2.2 Salinity and Sodicity

3.2.2.1 Soil layers. Topsoils had expected marked differences in saturation percentage, in that both ash and gypsum amendments reduced saturation percentage relative to the control. There was also a decrease with time, most pronounced in the early years.

EC, Na and SAR levels were different in response to treatment, amendment, year, and interactions of these. In summary, the following are the most important topsoil results after five years:

1. Treatment: Treatment 1 (no topsoil) was unsatisfactory throughout. Treatment 2 (topsoil over spoil) was better than Treatment 1 but inferior to Treatments 3 to 7 with subsoil. As of 1986, topsoils in Treatment 2 had highest EC, Na and SAR levels, due to upward movement of sodium from the spoil or limited leaching, or both. Treatment 6 topsoil ranked next and was higher in EC, Na and SAR than all others which were more or less similar. There are no clear differences in topsoils overlying B+C versus C subsoil materials.
2. Amendment: While ash causes trafficability problems, it clearly helps to improve topsoil chemical and physical properties. In ranking amendments, ash is usually superior as follows:
    - a. EC, ash < control < gypsum
    - b. Na, ash < control < gypsum
    - c. SAR, gypsum < ash < control

   Gypsum is obviously effective in reducing SAR whereas ash having low salt contents "dilutes" the soil and effectively enhances infiltration, leaching and thereby reduces EC and Na levels.
3. Time: EC, Na and SAR all decreased over the five-year period, with the major declines occurring in the last couple years.

Upper subsoils also have differences in saturation percentage, EC, Na and SAR as follows:

1. Treatment: Saturation percentage of C materials is higher than of B+C mixes.
2. Amendment: Amendments are ranked the same as in topsoils for levels of EC and Na, indicating enhanced leaching in upper subsoils likely due to superior physical properties in the topsoil. As of 1986, SAR levels in upper subsoils did not differ among amendments.
3. Time: Linear and quadratic contrasts are significant for saturation percentage, EC, Na and SAR and show that:
    a. saturation percentage decreased with time and levelled off in the last two years.
    b. EC increased with time then appeared to be levelling off.
    c. Na and SAR increased, peaked in 1984, and then decreased but in 1986 were still above initial levels.

Caution is advised in interpreting the technical significance of these results due to effects of declining saturation percentage over time. When saturation percentages are adjusted to be constant, EC and Na levels in the early years become relatively higher. The overall effect is then towards gradually improving upper soil quality over five years rather than initial degradation followed by improvement. Using reported results, the 1984 peaks in EC, Na and SAR may reflect the "salt front" moving downward. Using adjusted saturation percentages and corrected EC and Na values, it appears that the upper subsoils could have continually improved, in spite of salts moving through. The adjusted values therefore portray a more favorable land reclamation scenario.

Lower subsoils changed with time. Saturation percentages decreased mostly in the second year. EC increased considerably from 1982 to 1984 (6 to 9) then appeared to level off. Na and SAR levels also increased from 1982 to 1984 and declined since but in 1986 they were still above initial levels.

When adjustments are made to standardize saturation percentage the pattern for EC and Na levels remains similar in that levels peak in 1984 but the magnitude of the peak is reduced from about 3 units to 1 unit EC.

With or without adjustments, final EC, Na and SAR values are slightly or moderately higher, respectively, than 1982 values, indicating increasing salinization of the lower subsoil.

The difference between lower subsoils and upper subsoils revealed significant differences in saturation percentage, EC, Na and SAR due to treatment and amendment effects. Treatment 4 (B+C material) showed a greater difference in saturation percentage than Treatments 5, 6 and 7 (C material), and a greater difference in SAR than Treatment 7 (ash below subsoil). Ash amended plots had the greatest differences in EC and Na levels indicating more leaching than on gypsum or control plots.

The presence of calcium salts and moderate to high EC levels will have an ameliorative effect on SAR, that is, to prevent soil dispersion. Early indications are that declines in EC levels in topsoils and subsoils are accompanied by decreases in Na concentrations and SAR thereby permitting gradual soil reclamation as leaching progresses.

3.2.2.2 Treatments. Treatment effects are related to material composition. Treatment 1 (spoil) was unsuitable as a growth medium. Treatment 2 (topsoil over spoil) was better than spoil alone but inferior to treatments with subsoil. Other treatment differences are minor and do not affect soil quality, other than depth.

3.2.2.3 Amendment. Effects of ash and gypsum are clearly evident in the topsoils and upper subsoils. EC and Na levels are lowest in ash followed by control and gypsum. Gypsum is effective in lowering SAR levels, especially in the topsoil.

The results of treatment and amendment effects on soil quality in 1986, based on EC and SAR are summarized as follows:

1. Treatment 1: Unsuitable
2. Treatment 2: topsoil: Ash - Good, Gypsum - Poor, Control - Fair
   spoil: Unsuitable in all
3. Treatments 3 to 7: topsoil: Ash - Good, Gypsum - Fair, Control - Fair
   subsoils: Unsuitable due to excessive SAR
   spoils: Unsuitable due to excessive SAR

3.2.2.4 Special features. Leaching of topsoils in Treatments 3 to 7 occurred in the early years then levelled off. This resulted in initially increasing salinity in upper subsoils, which peaked in 1984, and subsequently declined. SAR in upper subsoils was excessive making these materials Unsuitable but with continued leaching they should improve. Lower subsoils degraded over time but the rate of deterioration appears to have been levelling off.

The surface ash amendment proved to be very beneficial by improving the rooting environment and enhancing leaching.

Other soil properties are given in Table 54 for control plots of Treatments 4 and 5.

Overall, salinity in the profiles increased according to lab results. Comparing sums of EC for all sampled intervals in control plots, 1982 and 1986, indicates:

1. a 35 to 40% increase in Treatments 4, 5, 6;
2. a 65% increase in Treatments 3 and 7; and
3. a 100% increase in Treatments 1 and 2.

On this basis, the deeper profiles have salinized less than shallower profiles. Caution is advised in interpreting these results because when adjustments for saturation percentage differences over time are made conclusions are very different.

Table 54. Soil chemical properties for control plots, Treatments 4 and 5, Torlea Soil Experiment, 1986.

Depth (cm)	pH	EC	SAR	Ca	Mg	Na	K	SO_4	Cl	Sat%
		mS/cm		--------------		me/L		------------		
					Treatment 4 (20 cm A/45 to 55 cm B+C/Spoil)					
TS 0 to 20	7.5	1	5	5	2	9	0.6	2	1.5	59
SS 15 to 40	7.6	6	15	18	10	51	0.5	61	1.0	67
30 to 70	7.7	10	19	31	18	93	0.7	126	0.9	70
SP 45 to 95	7.7	6	32	6	2	61	0.7	62	0.3	146
105 to 130	7.7	6	32	4	2	52	0.6	50	0.2	157
					Treatment 5 (20 cm A/75 to 90 cm C/Spoil)					
TS 0 to 20	7.3	2	7	5	2	14	0.4	5	2.2	57
SS 15 to 40	7.6	9	16	25	15	73	0.9	105	0.8	89
30 to 55	7.7	9	16	28	17	78	0.9	115	0.5	81
45 to 70	7.7	9	17	25	14	74	0.8	103	0.3	76
60 to 115	7.8	8	20	19	10	70	0.9	92	0.4	101
SP 75 to 130	7.4	8	32	9	4	80	0.9	84	0.4	136
140 to 155	7.7	7	30	9	4	74	0.9	76	0.5	153

All values are means of 3 replicates.

3.2.3 Soil Moisture

Soil moisture supply is examined in terms of four major factors:

1. Availability: Soil moisture supply was inadequate more than half the time throughout all topsoils and subsoils. Spoil materials were moist 50 to 90% of the time. Because reading depths were based on theoretical depths to material interfaces, the lowest readings which were to be in spoil may actually be in subsoil. Therefore, caution is advised in interpreting results in Table 29.
2. Water tables: Maximum soil moisture levels never exceeded field capacity; hence, there is no evidence of perched water tables.
3. Amendment effects: Topsoil moisture levels, especially on ash plots, appear higher than subsoil moisture levels. This may reflect an underestimate of wilting point, or effects of monitoring following showers which only moistened topsoil, or less runoff from ash plots and better moisture storage.
4. Soil Development: If ash amended plots are truly more moist due to increased infiltration then more effective leaching in the topsoils and upper subsoils would be expected. Examination of topsoil and upper subsoil EC and Na levels indicates that ash plots have the lowest levels - confirming more effective leaching.
5. Soil Depth: It is expected that treatments with deeper subsoils would hold more moisture and should therefore contribute to higher yields. This yield pattern is evident, but not significant, in progressing from Treatments 3 to 6, 25 to 100 cm of subsoil, respectively.

3.2.4 Bulk Density

Examination of density data indicates important findings:

1. Topsoils: Densities in 1987 averaged 1.16, 1.10, and 1.12 g/cm^3 for ash, gypsum and control plots, respectively. These differences are not significant, nor are changes across treatments. However, these densities are considerably lower than those of topsoils in the other experiments. A possible explanation is that the topsoils for this experiment were derived from original soils under native range whereas the others originated from cultivated fields. It is not known whether these topsoils were derived from native Torlea soils, or perhaps from other, better soils.
2. Subsoils: Subsoil densities in this experiment averaged 1.09 g/cm^3 in upper subsoil and 1.28 g/cm^3 in lower subsoil which are considerably lower than those of the other experiments. This may be attributed to material origins, to different reclamation techniques or to different subsoil moisture contents during construction. It was reported (Techman Engineering Ltd. 1982) that some of the Torlea Experiment plots were constructed in winter as conditions became too wet after the other experimental plots were constructed, during the preceding summer. If Torlea subsoils were considerably drier than those of other experiments during construction, the soils would have been less susceptible to compaction and there may have been less traffic to cause compaction under drier working conditions. Another possible explanation for lower densities is that the Torlea plots are narrower than others and may have had less traffic and less compaction during construction.
3. Spoils: Bulk densities of the spoil are similar to those of other experiments, averaging 1.31 g/cm^3 in 1987.

Soil densities in the Torlea Soil Experiment appear to have increased from 1983 to 1985 then decreased in all layers. This pattern is inconsistent with results of the other experiments.

3.2.5 Root Distribution

In all topsoils there were plentiful to abundant roots, which is comparable to findings in other experiments and to cultivated agricultural soils. Amendment effects were significant in that there was limited growth on Treatment 1 (spoil) plots with ash applied but essentially no growth on gypsum and control plots. On other treatments, rooting in topsoils was similar on all amendments. Trafficability was poor on all plots with ash amendment but once forages were established this was no longer a problem.

In Torlea subsoils, there generally were plentiful roots to 40 to 60 cm depth below surface. Rooting within Torlea subsoils was better than in the Subsoil Depth or Bottom Ash experiments. This is probably attributable to lower bulk densities in the Torlea subsoils, in spite of salinity and sodicity levels in Torlea subsoils being higher than in subsoils of the other experiments.

Rooting into spoils is limited to the upper 15 cm or so in treatments with spoil below about 75 cm. In shallower soils, there were few roots penetrating 50 to 75 cm into spoil.

In some instances, the rooting was deeper under gypsum or ash amended plots but no consistent pattern related to treatment could be defined.

3.3 BOTTOM ASH EXPERIMENT

3.3.1 Crop Yields

3.3.1.1 Forages. As in other experiments, forage yields declined with time. This appears to be related to rainfall as explained under the Subsoil Depth Experiment. The buried gypsum or ash layers at the subsoil-spoil interface did not significantly affect yields overall, however, the deepest subsoil plus ash, Treatment 5, had the highest average yields.

Bottom Ash forage yields averaged 2250 kg/ha and are considerably higher than control yields from Solonetzic soil study plots, varying from about 130% to over 190% of the undisturbed yields. Yields from plots treated with 3-layer plowing are similar and vary from 80% to 120%. The 3-layer plow treatment may approximate the reclaimed mine land situation, since it mixes B and C horizons while retaining the topsoil. Farmers' yields were slightly higher (3190 kg/ha) than Treatment 5 yields (2890 kg/ha). Recognizing the limitations of the comparative yield data, it is evident that Bottom Ash plot yields compare favorably.

3.3.1.2 Cereals. Grain yields were usually very poor due to low rainfall and restricted rooting depth. There were treatment, year, and year x treatment effects at a low level of significance ($p = 0.10$). Treatments 2 and 4 yielded less than the others. Highest yields were obtained in 1985 and lowest in 1983, as in the Subsoil Depth cereal plots.

Cereal yields are very poor compared to control yields from Solonetzic soil study plots. The highest yielding Bottom Ash treatments averaged over the 5 years are only 50% of the Solonetzic study plot control wheat yields, and 35% of farmers' regional yields. Highest Bottom Ash yields were obtained in 1985, as in the Subsoil Depth Experiment; however, they were only about 70% of yields on Solonetzic study control plots, and 50% of farmers' regional yields. Because cereal crops were so poor on the Bottom Ash plots, the treatment effects on yields must be applied with extreme caution.

3.3.2 Salinity and Sodicity

3.3.2.1 Soil layers. Topsoils changed over time and there were differences due to crops. Saturation percentage, EC, Na and SAR all decreased resulting in Good topsoil quality throughout in the last 2 years. Earlier topsoil quality was Fair. Topsoils under cereals had slightly higher EC, Na and SAR than under forages which may be attributable to different rates of leaching, evapotranspiration or mixing with subsoil during cultivation.

Subsoils also changed in all parameters. Saturation percentage declined, mainly in the first two years. Statistical analysis indicates significant linear and quadratic contrasts which show that EC, Na and SAR levels initially increased, peaked in 1984, then declined slightly but remained above original values. If adjustments are made to compensate for declining saturation percentage, then the EC, Na and SAR increases are not as pronounced and final values are similar to original ones. A comparison of gypsum at the subsoil/spoil interface versus the control indicates higher SAR in subsoil above the gypsum; hence, gypsum appears to be detrimental in that it tended to decrease the quality of root zone with respect to SAR. Note that because subsoils are about 25 cm thick, only one depth interval representing the entire layer was sampled. In fact, it is likely that the upper portion of this layer improved while the lower portion degraded. Caution is therefore advised in comparing these results with those of upper and lower subsoils in the other experiments.

Spoils remained Unsuitable but changed in response to treatments and time. Highlights as of 1986 include:

1. spoil below gypsum had lower saturation percentage and SAR than in control, and
2. spoil EC and Na levels decreased with increasing thickness of buried ash.

Spoil minus subsoil comparisons indicate overall statistical differences in all parameters reflecting material characteristics. Crop effects are of interest in that differences were greater under forage than cereal for EC and Na. Note that EC and Na levels in subsoil are greater than in spoil, but the differences are minor in practical terms (< 1 unit EC, 4 units Na).

3.3.2.2 Treatments. Gypsum (Treatment 2) at the subsoil/spoil interface was detrimental when compared to control (Treatment 1) in terms of subsoil SAR. Buried ash layers increased the rooting zone thickness and this was beneficial. Spoil EC, Na and SAR declined with increasing ash thickness which reflects less leaching of sodium salts from above or greater leaching through the spoil.

Visual examination of EC and SAR data across years and treatments suggests that Treatments 4 and 5 had, in 1986, slightly better topsoils and subsoils than other treatments although subsoil EC levels were still around 8 mS/cm.

Average 1985/1986 SAR less than 12 extended to 40 cm in Treatments 1, 4 and 5, but only to 15 cm in Treatments 2 and 3.

While there was leaching of salts from topsoils there was no overall increase in salts in all profiles between 1982 and 1986, based on the sums of EC for sampled layers adjusted to standard saturation percentages.

3.3.2.3 Special features. Topsoils have improved with time. Subsoils initially degraded but then improved and should continue to do so. Spoils improved slightly. It appears that Treatments 4 and 5 are slightly better in terms of topsoil and subsoil quality but more time is needed to determine whether recent trends will become statistically and practically meaningful.

3.3.3 Soil Moisture

Soil moisture levels were tabulated, and interpreted in terms of four key aspects:

1. Availability: Soil moisture availability in the root zone appeared to be slightly higher in Treatment 2 (gypsum) than Treatments 1 (control) and 3 (5 cm buried ash), which in turn, were higher than Treatments 4 and 5 (15, 45 cm buried ash). Higher moisture supply in Treatment 2 may reflect higher SAR levels and lower moisture extraction by plants. Caution is advised in interpreting the moisture data due to effects of:
   a) buried ash layers on probe readings;
   b) disregarding different wilting point and field capacity of ash; and
   c) uneven depths of buried ash layers combined with averaging of values from different replicates.

2. Water tables: Nearly all moisture levels were below field capacity, and those which exceeded it were well below saturation percentage. Therefore, it is thought that no temporary water tables occurred within the monitoring depths during the growing seasons.
3. Crop effects: Treatments 1, 2 and 3 were slightly drier under forages than under cereals. This reflects higher evapotranspiration and deeper rooting by forages. Treatments 4 and 5 were always very dry under both crops.
4. Soil development: The buried ash layers appear to have helped make the upper root zone drier, perhaps by allowing better root growth at depth, or by serving as a drain when there was percolation down through soil cracks. The latter condition is supported by declining EC and Na in spoils in Treatments 4 and 5, possibly due to leaching by water rapidly percolating through cracks and fissures in the upper profile.

3.3.4 Soil Density

Topsoil bulk densities are considered to be within the normal range for agricultural soils in the area. Cereal and forage plot topsoil densities averaged 1.42 g/cm^3 and 1.44 g/cm^3, respectively, in 1987.

Subsoil bulk densities were high averaging 1.59 and 1.70 g/cm^3 for cereal and forage plots in 1987. There were changes over time which suggest natural amelioration was occurring, but this trend is questionable in light of results of gravimetric samples taken in 1987 indicating subsoil densities of 1.75 g/cm^3. Crops did not exert a significant effect either, even though soils under cereals were generally more moist than those under forages. This supports findings elsewhere that wetting and drying is ineffective in alleviating compaction. Any improvements to soil structure and increased leaching that might be expected or measured under deep rooted forages are not reflected in the density studies. It may be that minor improvements occurred but the monitoring techniques were not sensitive enough and the variation too great to detect significant changes.

3.3.5 Root Distribution

Rooting patterns in Bottom Ash forage plots indicated a response to gypsum and ash treatments in that the occurrence of plentiful roots was about 10 cm deeper into the subsoil than in the control. This may reflect better upper subsoil leaching in the treatments producing more permeable deeper materials.

Cereal plots all had abundant roots in topsoils but only few in upper subsoils to about 40 cm in all treatments.

3.4 SLOPE DRAINAGE EXPERIMENT

3.4.1 Crop Yields

Forage yields were not affected by slope angle or aspect but yields did increase downslope. Year was significant: yields were highest 1985, lowest 1986, and intermediate 1982 to 1984. These yields were above those which are subjectively comparable at best, on undisturbed forage controls of Solonetzic soil study sites. However, yields were below those obtained on 3-layer plow plots and farmers regional yields as summarized below:

	Yields (kg/ha, 1982 to 1986)			
Source:	Upper	Middle	Lower	Mean
Slope Drainage	1650	1820	1860	1777
Solonetzic study undisturbed control				1590
Solonetzic study 3-layer plow				2540
Agricultural Reporting Area No. 4A				3200

3.4.2 Salinity and Sodicity

3.4.2.1 Soil layers. Topsoils improved over the five-year term. Position effects were important in that, going from upper to lower slope, there were increases in saturation percentage, EC and Na. Year x position interactions indicate that the lower slopes were initially highest in saturation percentage, EC and Na and they declined the most to match other positions in the end. Slope angle comparisons indicate that 10° slopes had a higher EC than 5° slopes, 2.0 versus 1.4 mS/cm, respectively. These data indicate that topsoils improved from Fair to Good in lower positions and were always Good in upper and middle positions. Standardizing saturation percentages indicates greater improvement in the early years.

Upper subsoils changed with time and in response to treatments. Saturation percentage and EC declined with time. Year x treatment interactions indicate saturation percentage of Treatment 3 (5S) declined more than others after year 1. EC, Na, and SAR of Treatments 2 (10N) and 3 (5S) were considerably higher than other treatments in the last 2 years, even though all started at similar levels. Mean EC for all treatments increased from 1982 to 1984, then decreased. Adjustment of saturation percentages indicates that EC would have been steady the first three years and reduced by 1 unit in the last two years. Upper subsoil quality in Treatments 1 and 4 was Poor, in 1986, due to moderately high EC and SAR. Treatments 2 and 3 had Unsuitable upper subsoils due to SAR exceeding 12, in 1986. Over time Treatments 2 and 3 degraded: 1 and 4 improved slightly.

Lower subsoils changed in response to position and year effects. Saturation percentage and SAR decreased markedly in the lower position from 1984 to 1986. EC increased from 1984 (8.3 mS/cm) to 1986 (9.5 mS/cm actual, or 8.9 mS/cm adjusted) indicating salinization.

Lower subsoils were Unsuitable throughout the years due to excessive SAR values, but there was slight improvement in SAR in the lower position in spite of increasing EC.

Spoils were compared for the last three years. Saturation percentage increased from 1984 to 1985 and decreased in 1986. EC and Na decreased then increased at the corresponding time (with or without adjustments). SAR declined with time. Regardless, spoils were Unsuitable due to excessive SAR and saturation percentage in all years.

Lower subsoil minus upper subsoil differences in all parameters were significant in response to treatments, or positions, or year, as follows:

1. Saturation % - steeper slopes had smaller differences when facing north, but larger differences when facing south. This implies that drier conditions on steep south aspects enhance leaching which is the opposite of what one would expect. Lower

slopes had higher saturation percentage differences than upper slopes. This may be a reflection of shallower subsoils in lower positions, and perhaps an influence of higher sodium levels.

2. EC, Na, SAR - differences were greater in lower than in upper positions, indicating more leaching of upper subsoil, greater diffusion or accumulation in lower subsoil, or both, in lower positions. For Na, this difference increased with time. For SAR, the 5N and 10S treatments had greater differences than the others.

Spoil minus lower subsoil differences in all parameters were also significant in response to position and year, but not treatment:

1. Saturation % - differences peaked in 1985 in the upper and lower positions.
2. Na - differences indicate that Na levels increased with time in lower subsoils relative to spoils. This trend became more pronounced proceeding downslope.
3. SAR - differences declined downslope and with time, however, declining differences were mainly in upper and middle positions.

Spoils were inferior to lower subsoils in all parameters.

3.4.2.2 Treatments and positions. Topsoils in 1986 were Good, lower subsoils and spoils were all Unsuitable (SAR); therefore, important changes were confined to the upper subsoils. Treatments 1 (5N) and 4 (10S) had Poor (SAR) upper subsoils: Treatments 2 (10N) and 3 (5S) had Unsuitable (SAR) upper subsoils. From 1982 to 1986, Treatments 2 and 3 remained unchanged while 1 and 4 improved.

Positions are important in that topsoils were initially poorest in lower positions but improved in time to match upper and middle position topsoils. This may be related to drainage improvements in the vicinity of the plots in 1983 rather than to position effects per se. Positions did not affect upper subsoils. Lower subsoils changed in SAR only, such that SAR improved in the lower slopes over the last three years.

3.4.2.3 Special features. Leaching of upper profiles occurred. Topsoils improved throughout, while upper subsoils improved in Treatments 1 (5N) and 4 (10S). No meaningful changes in terms of soil quality occurred in the lower subsoils and spoils but the trend in later years indicates lower subsoils were degrading in terms of EC while improving in terms of SAR.

3.4.3 Soil Moisture

Soil moisture levels were tabulated, and interpreted in terms of three important implications:

1. Availability: Topsoils had readily available moisture about half the time. Subsoils in upper, middle and lower slopes had readily available moisture <20%, about 20%, and more than 50% of the time, respectively. Spoils were always moist. South aspects were slightly drier than north aspects and steeper slopes were drier than gentler slopes.
2. Water tables: As in all other experiments, moisture contents seldom exceeded field capacity and there was no evidence of water tables. Therefore salinity changes may be attributed to unsaturated flow downslope. There may also be side effects in lower positions caused by lateral surface flow from adjacent compound lands.
3. Soil development: Wetter lower positions reflect runoff from upper slopes as indicated by the pronounced improvements in topsoil quality in lower positions. In addition, there may be subsurface, unsaturated flow downslope.
4. Groundwater regime: The absence of shallow water tables indicates that the lower slopes may be regarded as "recharge" sites rather than "discharge" sites.

3.4.4 Soil Density

Topsoil bulk densities are considered to be normal for cultivated soils in the region. Subsoils have very high densities, averaging about 1.6 g/cm^3. Densities exceeding about 1.4 g/cm^3 and consequent decreasing porosities are known to restrict root growth and reduce yields of some crops; therefore, crop productivity is probably inhibited by subsoil compaction which occurred during reclamation.

Spoil densities are comparable to till parent materials with similar texture, but high saturation percentage, high sodicity and related poor soil structure may restrict water and air movement and rooting.

3.4.5 Root Distribution

There is an abundance of roots in the topsoil, grading to few roots at about 60 cm depth. Maximum depth of rooting was found to be about 145 cm, but very few roots extended more than 15 cm into spoil.

4. CONCLUSIONS AND RECOMMENDATIONS

The four experiments monitored for five years have provided important information about mine land reclamation of saline and sodic materials for agricultural use. Several clear and conclusive statements can be made at this time but there are also some important issues requiring further study and more time is needed to establish equilibrium conditions. Each experiment is addressed separately and then they are discussed as a group.

4.1 SUBSOIL DEPTH EXPERIMENT

4.1.1 Crop Yield

Null Hypotheses:

1. Crop productivity on reclaimed sodic spoil is not a function of subsoil depth (subsoil is defined as non-sodic material placed between spoil and replaced topsoil). If rejected identify optimal subsoil depth.
2. Forage and grain crops will not respond differently to varying subsoil depths. If rejected identify optimal subsoil depth for each crop.

4.1.1.1 Forage. Forage production proved to be related to subsoil depth such that the deeper the subsoils, the greater the yields; therefore, both the null hypotheses are rejected with respect to forage production. Greater soil depths provided progressively deeper rooting zones and larger moisture storage capacities. While this is true for the depths of subsoils used in this experiment, it must be understood that yields would level off as subsoil depths exceed the maximum rooting depth, in this case, for alfalfa. Roots did not penetrate spoil more than about 15 cm.

One way of looking at yields on this experiment is to determine yield response per unit increase in subsoil thickness. Five year forage yield averages increased almost linearly between 65 cm to 335 cm of subsoil with a yield response of 3.5 to 4.4 kg/ha per cm of subsoil added. As mentioned above, however, this relationship would not continue beyond the rooting depth. Simple calculations of measured benefits of increasing subsoil thickness, using the 0.0 m subsoil treatment as a base, are as follows:

Treatments	1	2	3	4	5	6
Topsoil (cm)	15	15	15	15	15	15
Subsoil (cm)	0	25	65	135	165	335
Yield (kg/ha)	2220	2150	2450	2810	2910	3480
Incremental Yield (kg/ha)	--	(-70)	230	590	690	1260
Incremental Yield/cm Subsoil	--	--	3.5	4.4	4.2	3.8

Topsoil alone over spoil yields 2220 kg/ha, and assuming that applications of 65 cm subsoil or more contribute to greater yields, then the ratio of incremental yield (treatment yield with subsoil minus treatment yield without subsoil) to subsoil thickness indicates the yield returns per cm of subsoil. The data above indicate that a thin layer (25 cm) of subsoil is of no advantage.

There is no optimum subsoil depth based on yields of this experiment alone. If one chooses a target yield then the corresponding subsoil depth can be determined. A major problem in this area is choosing the target yield.

Forage yields from the Soloneztic Study plots are too sparse (only 1 site 1983 to 1986) to be scientifically reliable. In a subjective comparison, Treatment 3 yields match those on deep plowed Solonetzic soils: yields on all Subsoil Depth treatments exceed the check yields in the Solonetzic Study.

Farmer's yields from a wide range of soil types and climatic conditions representing Agricultural Reporting Area 4A, were 3190 kg/ha (1983 to 1986 mean) and the average for 1972 to 1979 was 3140 kg/ha which is between the averages for Treatments 5 and 6. If these are to be the target yields then a minimum of 235 cm of subsoil is recommended.

Another consideration is the formation of a salt accumulation layer at about 40 to 100 cm. This depth of salt accumulation is similar to that in natural soils in the area. If the salt concentration within this depth interval becomes a limitation to root growth, then the advantages of subsoils exceeding depths of 100 cm (or perhaps less) may disappear.

Literature findings indicate that recommended depths of subsoil in North Dakota vary but generally should be at least 60 cm and preferably 90 to 120 cm (Doll et al. 1984).

4.1.1.2 Cereal. Grain yields were generally very low and are considered to be unsatisfactory on all treatments. Reclamation for grain production has been unsuccessful in this experiment. Experimental yields were 30 to 40% below those found in other nearby research studies conducted at the same time and they are only 40% of regional averages. Low rainfall in most years contributed to crop failures but a major limitation appears to be quality of the upper subsoil for cereal crop rooting. Subsoil densities were very high and combined with moderate salinity and sodicity were limiting yields across all treatments. It is believed that root penetration was restricted and moisture availability to plants thereby reduced. Crop growth was therefore largely governed by topsoil depth and quality. Incremental gains attributable to deeper subsoils ranged from 8 to 24% higher than the topsoil over spoil treatment, but in absolute terms yields were still very low. Grain yields were highest on 65 and 135 cm of subsoil over spoil which was significantly better than no subsoil. Yields on other treatments were intermediate. In 1982 and 1985, when amounts and distribution of rainfall was better during the growing season, yields were higher but still below farm averages.

On the basis of the literature review, at least 80 cm of topsoil plus subsoil over spoil is recommended for grain production.

4.1.2 Soil Salinity

Null Hypothesis:

1. Salts will not migrate from sodic spoil into subsoil. If rejected quantify the effect.

This hypothesis is rejected. The data indicate that salt concentrations have increased in the 15 cm subsoil layer immediately over spoil. The increases in EC and SAR have been about 1 mS/cm and 2, respectively. This change is small but it resulted in a decrease in subsoil quality rating from Poor to Unsuitable over time and also with respect to subsoils higher in the profile.

The experimental results suggest increased salt concentration in the lower subsoil due to upward sodium movement by diffusion as well as accumulation resulting from leaching of salts from higher in the profile. As widely reported in the literature, the salt concentration above the spoil is confined to the 15 cm sample interval. Further upward salt movement should not be considered a threat in the absence of a water table within at least 3.5 m of the ground surface. If subsoils are shallow, say 65 cm to spoil, then degradation of 15 cm of subsoil above the spoil would reduce the root zone thickness for deeper rooting crops to 50 cm, if not constrained by other factors. Deeper rooting crops such as forages should benefit from deeper subsoils. While this experiment originally focussed on the depth to subsoil/spoil interface, there were numerous other very important findings and these are discussed next.

4.1.2.1 Treatment effects. Soil salinity and sodicity changes occurred with time such that topsoils improved and in 1986 were Good, upper subsoils initially degraded (as topsoil salts were flushed through) and were later improving. Salt accumulation below 30 cm was becoming evident, resulting from leaching. In shallow treatments, this accumulation zone extended into the upper spoil; in deeper subsoils it continued to about 100 cm. More time is needed to determine whether this accumulation zone moves deeper and whether it becomes more pronounced. A second zone of salt accumulation was developing in deeper treatments (165 cm or more of subsoil), beginning 15 cm above the spoil and continuing into the spoil. This concentration in lower subsoil is considered to be caused by leaching from higher in the profile, being restricted at the interface and possibly some upward diffusion. Effects of upward diffusion are expected to remain within 15 cm above spoil. In Treatment 4 (135 cm of subsoil), it appears that the upper salt accumulation zone ends just as the lower salt accumulation zone begins (about 100 cm depth). Treatments 2 and 3 have more pronounced salt accumulation zones - due to effects of leaching of upper horizons, restriction at the interface and diffusion from spoil below. Considering the above trends, it appears that Treatment 4 (15 cm topsoil and 135 cm subsoil over spoil) represents the depth of subsoil required to permit normal salt leaching and accumulation to occur without restriction attributable to spoil.

Given more time, if a more pronounced salt accumulation layer develops that limits the root zone, for example to 65 cm, and salt concentrations are excessive below 50 cm whether spoil begins at 80 cm (Treatment 3) or deeper, then more than 65 cm of topsoil plus subsoil (allowing 15 cm lower subsoil to salinize) may not be beneficial. The Halkirk Series unmined soil has a natural salt accumulation (EC = 10 mS/cm) from about 50 to 70 cm and no roots below this depth. If the reclaimed soils develop a concentrated salt layer roughly in this zone, then the 65 cm to spoil treatment would be adequate. However yields will be well below average farmer yields. Note that these limits are applicable in the absence of a water table within 350 cm: in landscape positions with shallower water tables (say within 200 cm) capillary rise of salts into the root zone could be expected and this could change the reclamation requirements in such areas.

Considering soil salinity, sodicity and forage yields (to meet farm averages) measured to date, a minimum of 15 cm of topsoil and 225 cm of subsoil over spoil is recommended. Increasing subsoil thickness to 350 cm has further benefited forage production. But more time is needed for a new "salinity" equilibrium to be established in the reclaimed profiles. If soil chemical and physical properties change, as expected, to prevent rooting below a moderately shallow depth, say 65 cm, regardless of depth to spoil below, then advantages of deeper subsoil may disappear.

It is the author's opinion that the main salt accumulation zone will develop in the 50 to 70 cm range as in unmined soils. This is based on observation of many deep soils (> 2 m over bedrock), in which lime or salt accumulations tend to be at similar depths in a given climatic region, regardless of differences in soil structure, texture (except perhaps very sandy soils) and density. This applies in areas of deep water tables.

Thus, in terms of salinity equilibria in the longer term, the 65 cm subsoil treatment is recommended. This allows 30 cm of subsoil material to "buffer" effects of restricted permeability of spoil or upward diffusion. Note, a 15 cm topsoil thickness is assumed.

4.1.3 Soil Moisture

Null Hypothesis:

1. The subsoil/sodic spoil interface will not interfere with the vertical movement of water. If rejected quantify the effect.

This hypothesis is conditionally accepted, subject to the following:

1. The soil moisture monitoring indicated that subsoils and spoil within monitoring depths were almost always below field capacity and never approached saturation, and this is expected to continue.
2. The high subsoil densities, and lack of good structure and continuous pores are a major constraint to downward water movement through the soil matrix so it is thought that deep percolation occurs mainly along cracks and fissures when there is heavy rainfall after a drought period. For example, a soil moisture increase at 150 cm depth could occur a few days after a 3 cm rainfall, even though moisture levels higher in the profile are below field capacity. It is also likely that cracks continue into the spoil or that there are more pores in the less dense spoil so that water movement beyond the lower subsoil would not be seriously retarded at the interface. The increase in salt concentrations above the spoil interface may reflect partial restriction in downward movement. But increased salts, especially Ca, below the interface confirms

that leaching continues into the spoil. However, if the spoil ever becomes saturated, its structure could change and the material could become less permeable. If it were to remain saturated capillary rise of salts could occur or if it dried again permeability may remain lower than at present. In either case, the null hypothesis would have to be re-examined.

3. If subsoil compaction is significantly reduced by natural, biological or mechanical amelioration, the subsoil should become more permeable and this could also change the moisture regime such that the spoil contact might interfere with water movement.

4.1.4 Bulk Density

When the experiments were designed and constructed, soil compaction was not considered to be a problem and there were no stated hypotheses for these experiments regarding soil density. It was thought that the replaced soils would be "loose" and they would "settle" over time and that densities would therefore be low initially and gradually increase. In fact, subsoil thicknesses are greater than originally specified to allow for settling.

This study made at least four very important findings concerning density:

1. The subsoil densities on all treatments are very high, averaging more than 1.70 g/cm^3. Literature findings indicate that, as a rule of thumb, clay loams with densities greater than 1.55 g/cm^3 will severely impede root growth and reduce yields (Bowen 1981).
2. As of 1987, there were no differences measured in soil densities attributable to crops even though forages produced well while cereal yields were very low.

3. There was a trend indicating natural amelioration of compaction over the monitoring period; however, reliability of the probe measurements is questionable. Gravimetric samples taken in 1987 confirm that soil densities remained very high averaging 1.34 g/cm^3 in the topsoil, 1.80 g/cm^3 in the upper 30 cm of subsoil, and 1.77 g/cm^3 in the 30 to 45 cm layer of subsoil.
4. Method of construction affects soil compaction. Subsoil densities at the BRSRP site are much higher than those at the Highvale site, 1.20 to 1.40 g/cm^3 in subsoils, (Monenco Consultants Ltd. 1987). At BRSRP the "take and put" system was employed using heavy mining equipment whereas at Highvale the subsoil was "backfilled" using a small dozer and bucket. The latter approach was used primarily to gain better control of subsoil thicknesses, a problem experienced at the BRSRP, but it is now evident that an important side-benefit was reduced compaction.

4.1.5 Root Distribution

Cereal roots were confined to the topsoils and upper subsoils. Had the roots been able to penetrate the subsoil deeper, the crops could have used more "available" moisture and produced better.

Forage roots penetrated some 15 cm into spoil or to about 140 cm into subsoil, whichever was shallower. Deeper rooting zones contributed more moisture and this is reflected in higher yields.

4.1.6 Interactions

It appears that moisture availability to the crops is the principal factor governing yields and differences among treatments. For forages, yields increased linearly as subsoil thickness increased and this is attributable to increased moisture storage. However, it is expected that a salt accumulation zone will develop at about 50 to 70 cm which could restrict deeper rooting.

When this happens, yields could be limited to those of Treatment 3, and be well below farm averages. Cereal yields did not respond to increasing subsoil thicknesses due to severe compaction in subsoils restricting rooting primarily to topsoils and upper subsoils.

To successfully reclaim these lands more attention may need to be given to developing a better physical environment, specifically, to improve structure, to reduce density, and to increase water storage capacity in the upper 50 cm. If this can be accomplished in a practical and economical manner, then a subsoil thickness of 65 cm should be a minimum in terms of salinity equilibria, moisture supply for forages, and suitable rooting zone for cereals. The optimum depth may be 90 to 120 cm, with reasonable soil densities, in the short term prior to development of a salt accumulation zone. Rates of natural amelioration of compaction are considered to be too slow to leave reclaimed lands in a state similar to that of the plots.

4.2 TORLEA SOIL EXPERIMENT

4.2.1 Crop Yields

Null Hypotheses:

1. Forage crop performance on reclaimed sodic spoil is not influenced by application of black solonetzic horizons in various thicknesses and combinations. If rejected, identify best thickness and combination of horizons.
2. Forage crop performance on various thicknesses and combinations of black solonetzic horizons is not influenced by surface application of gypsum or bottom ash. If rejected, quantify the effect.

4.2.1.1 Treatment effects. The first null hypothesis is rejected. Treatment effects proved to be important and key findings are:

1. Treatment 1, no topsoil over spoil, was totally unsatisfactory as there were zero yields except on the ash amendment which yielded very poorly.

2. Treatment 2, topsoil over spoil, had poor yields compared to remaining treatments.
3. Treatments 3 to 6 produced good yields and also increasing depths of subsoils contributed to higher yields. Subsoil thickness appeared to be more important than different mixes, and buried ash in Treatment 7 was detrimental to yields, but none of these were statistically significant.
4. Yields on Treatments 3 to 7 average higher than forage yields on the other BRSRP experiments.

The foregoing indicates that Treatments 3 to 7 were superior to 1 and 2. From a yield perspective, the highest yielding treatment would be best but all treatments with topsoil over subsoil over spoil exceed 1983 to 1986 yields reported by other studies and by farmers in the area:

Treatment (subsoil horizon mix)	2(Spoil)	3(B+C)	4(B+C)	5(C)	6(C)	7(50 cm C/30 cm ash)
Topsoil (cm)	20	20	20	20	20	20
Subsoil (cm)	0	25	50	80	110	80
Yield (kg/ha)	1870	3510	3700	3760	3810	3170

Solonetzic Study: Natural soil yield (kg/ha)	1525
Solonetzic Study: Deep plowed soil yield (kg/ha)	2477
Torlea Soil study at Paintearth mine, reference yield (kg/ha)	1370
Regional farm yields (ARA 4A) (kg/ha) (1982 to 1986)	3190

There is a 5% increase in yields from Treatment 3 to 4 attributed to 25 cm more subsoil but less than 2% increases from Treatments 4 to 5 or 5 to 6 for additional 30 cm increments of subsoil. Therefore, from a yield perspective alone, Treatment 4 (50 cm subsoil) is advised.

4.2.1.2 Amendment effects. The second null hypothesis is also rejected. Amendments were important and showed that:

1. Crop yields across Treatments 2 to 7 were best on ash (3620 kg/ha) amended plots, followed by gypsum (3290 kg/ha) then control (2990 kg/ha). This is about a 10% difference between each. While treatment x amendment interactions were not significant, the relative increases in yields suggest the ash or gypsum surface amendments are much more effective than

30 cm increments of subsoil beyond 50 cm. The benefits of ash, however, are partly negated by poor trafficability and the duration of benefits or problems under repeated cultivation is not known.

4.2.2 Soil Salinity

4.2.2.1 Treatment effects. Soil chemical properties (EC, SAR) and soil quality (Unsuitable) were unacceptable in Treatment 1. Treatment 2 had Poor topsoil over Unsuitable spoil, due to excessive SAR. Treatments 3 to 7 had Poor or Fair topsoils at the beginning of the study and these improved to Good by 1986. Subsoils were Unsuitable throughout. Upper subsoils in Treatments 4 and 6 were improving in the latter years, but in Treatments 3, 5 and 7 they were degrading. Lower subsoils degraded in the first couple years then stabilized or improved slightly, but were Unsuitable throughout. There were no significant treatment differences in lower subsoil.

Therefore, trends indicate that Treatments 4 and 6 are superior. Treatment 4 has subsoil comprised of B and C mix. Treatment 6 was to have C material but its characteristics appear to be intermediate between B and C mix and C alone. Treatment 3 was also a B and C mix but it was degrading, perhaps due to shallow depth to spoil. For reclamation purposes, Treatment 4 is shallower (50 cm subsoil versus 110 cm for Treatment 6) and is thereby recommended. This is only 10 cm less subsoil than the minimum recommended in North Dakota (Doll et al. 1984).

4.2.2.2 Amendment effects. These were also important and EC, SAR and Na levels in topsoils and upper subsoils clearly show that the ash amendment is the best. Gypsum is ranked intermediate: EC and Na levels were highest in topsoils and upper subsoils, but SAR was lowest in the topsoils. Control plots had intermediate EC and Na levels but highest SAR in topsoils and intermediate EC and Na levels in upper subsoils. Over time as topsoils improved, differences in chemistry between amendments and the control were decreasing.

In upper subsoils, there were very minor differences between amendments initially, grading to most pronounced differences and increasing levels in 1984, then improvement and declining differences in the last couple years. Therefore, it appears that Ash followed by Gypsum helped to hasten soil improvement in the upper profile. More time is needed to establish the longer term equilibrium.

4.2.3 Soil Moisture

4.2.3.1 Treatment effects. The main differences among treatments are related primarily to depth of subsoil. Generally, the subsoils were droughty and spoils were moist, hence, the depth to moisture was dependent on depth to spoil. Since roots did not penetrate spoil more than 15 cm or so (perhaps due to restrictive chemical properties, structure and poor aeration) the moist spoil was of no advantage. It seems that in the Torlea Experiment deeper subsoils (> 65 cm) were not better in providing more moisture: climatic conditions were simply too dry. There do not appear to be any differences between horizon mixes.

4.2.3.2 Amendment effects. Ash amended plots apparently had more topsoil moisture, followed by gypsum and control. Three explanations are possible:

1. the ash distorts neutron probe readings so the topsoil moisture contents could be inaccurate;
2. more rainfall enters and is stored in the "sandier" topsoil and does not infiltrate into the subsoil as much as in the gypsum or control plots; and,
3. the ash amendment makes the topsoil treatment thicker and this functions as a better moisture reservoir.

Subsoils were driest in the ash amended plots, again followed by gypsum and control. It therefore is evident that moisture contents decreased with increasing yields. The soil improvements imparted by surface ash application enabled the forage crops to extract more moisture or more efficiently utilize scarce soil moisture to produce higher yields. The increased infiltration capacity of ash amended topsoils is probably a key factor in replenishing soil moisture, given the dependence on spring melt and rainstorms of short duration in this environment.

4.2.4 Bulk Density

Bulk densities of the Torlea Soil Experiment subsoils are considerably lower (around 1.3 g/cm^3) than those in all other experiments (around 1.7 g/cm^3). This may be the main reason for considerably higher forage yields on Torlea treatments with subsoils than in all other experiments, except Treatment 6 of the Subsoil Depth Experiment, even though EC and SAR levels on the Torlea soils are greater than those of other experiments.

4.2.5 Root Distribution

Rooting depth was governed by depth to spoil such that roots generally penetrated only about 15 cm into spoil. Amendment effects were clearly evident on spoil alone (Treatment 1) such that there was growth only on the ash amendment. Effects were not clearly evident in remaining treatments, although ash and gypsum seemed to promote deeper rooting in some plots. In the Torlea plots, plentiful roots were commonly found to 50 to 60 cm depth, where spoils were deeper. In the Subsoil Depth Experiment, there were only few roots below the topsoils to about 40 cm. The lower bulk densities in the Torlea plots are considered to be the major reason for this difference in rooting pattern.

4.2.6 Interaction

Considering crop yields, soil depth, salinity, subsoil density and rooting pattern it appears that the reconstructed Torlea Soils have more favourable moisture supplying capacity than soils of the other experiments. Higher yields were obtained on Torlea soils even though depths were shallower and subsoil quality was inferior as reflected by chemical properties. It is concluded that because of lower bulk densities and higher moisture supplying capacity, roots were able to extract either more moisture, available from precipitation, or extract it more efficiently, or both. As a result, energy was utilized for forage growth rather than deeper root growth. The ash surface amendment seems to have a positive effect in contributing to higher soil moisture storage and availability, in turn resulting in greater yields.

4.3 BOTTOM ASH EXPERIMENT

4.3.1 Crop Yields

Null Hypotheses:

1. Crop production is not affected by addition of bottom ash buffer layers between replaced subsoil and sodic spoil. If rejected identify optimal thickness of bottom ash layer.
2. Crop production is not affected by addition of a gypsum layer between replaced subsoil and sodic spoil. If rejected, quantify the effect.
3. Grain and forage crops will not respond differently to bottom ash or gypsum layers between replaced subsoil and sodic spoil. If rejected, quantify the effect.

4.3.1.1 Forage. All the null hypotheses are accepted: there were no statistically significant treatment effects. Only a linear decline over time was significant due to progressively drier weather, an aging forage stand or both. Therefore, over the five year period there were no advantages to adding gypsum or buried ash layers based on statistical findings. However, the average forage yields for 1983 to 1986 presented below indicate that Treatment 5 out-yielded Treatments 1 and 2 by over 40%:

Treatment	1 (Control)	2 (Gypsum)	3 (5 cm Ash)	4 (15 cm Ash)	5 (45 cm Ash)
Yield(kg/ha)	2015	1974	2416	2204	2892

n = 15, no significant differences

In conclusion, it appears advantageous to have a buried ash layer but it is not known whether the benefits are due to ash per se or to a greater depth to spoil. If the primary goal is ash disposal, then this type of burial is appropriate as reflected by higher crop yields.

4.3.1.2 Cereal. As with forages, there were no statistical treatment effects on yields; however, at a lower level of significance ($p = 0.10$), treatment, year and their interactions were significant. Controls out-yielded gypsum and Treatment 5 yielded best in 1984 and 1985. Average yields by treatment for 1982 to 1986 were:

Treatment	1 (Control)	2 (Gypsum)	3 (5 cm Ash)	4 (15 cm Ash)	5 (45 cm Ash)
kg/ha	735	604	733	520	748

n = 15, s.e. = 59.1, c.v. = 289, p = 0.05.

While 5 and 45 cm of buried ash in Treatments 3 and 5 did not affect yields compared to the control, Treatment 4 with 15 cm of buried ash yielded much less. This is thought to be due to other soil or hydrological limitations especially in Replicate 3 as there is no apparent reason for the ash to be so detrimental.

4.3.2 Soil Salinity

4.3.2.1 Treatment effects. There were few differences among treatments in this experiment, as follows:

1. In the planned comparison of buried ash treatments, topsoil EC was highest in Treatment 4, averaging 0.6 mS/cm higher. This difference is too small to explain the depressed yields.
2. Subsoils in the buried gypsum treatment had higher SAR than in the control. This is the opposite of what was expected and can perhaps be explained by variation in the original materials.
3. Spoil EC and Na levels decreased with increasing thickness of buried ash suggesting leaching of spoils under deeper ash layers. The gypsum treatment had lower saturation percentage and SAR than the control suggesting downward movement of gypsum. These differences in spoils are important in that they indicate that leaching is occurring at 40 cm to 55 cm without buried ash and deeper with buried ash. Because the subsoils were only 25 cm thick, upper and lower layers were not sampled separately. Results cannot distinguish possible leaching of salts in the upper and accumulation in the lower subsoil.

4.3.2.2 Crop effects. All topsoils in cereal plots had slightly higher EC, Na and SAR levels than forage plots. This is attributed to mixing of upper subsoil with topsoil during cultivation as well as more effective leaching under forage. However, by 1986 all values were very low and did not affect topsoil quality.

4.3.2.3 Time effects. Topsoils improved over time because salts were leached out. Subsoils degraded in the first couple years reflecting accumulation of salts from above, then improved in the latter years to near original levels reflecting leaching of salts through the subsoils. Continued monitoring is needed to establish whether further leaching occurs or a salt accumulation layer develops within the lower subsoil. In the future, upper and lower halves of the subsoil layer should be sampled separately, accepting that a 10 cm rather than 15 cm interval would be sampled.

4.3.3 Soil Moisture

4.3.3.1 Treatment and crop effects. In Treatments 1, 2 and 3, topsoils and subsoils had readily available moisture 20% more of the time under cereals than forages. In Treatments 4 and 5 this 20% difference applied to topsoils only, as subsoils under both crops were usually dry. The latter may be a result of better rooting or it may be due to interpretive errors caused by incorrect calibration of readings in buried ash layers.

While the spoils were moist most of the time, there was no evidence of saturated conditions and a perched water table. Lack of root penetration into the spoils indicates that plants cannot utilize this moisture. High SAR and Na levels in spoil may limit aeration, or be phytotoxic (very high Na:Ca ratio). Also, the conventional wilting point and field capacity moisture determinations may seriously underestimate percentages at which plants can extract the water.

4.3.4 Bulk Density

Topsoil densities are within the normal range for agricultural soils, but subsoil densities are excessive. The forage crops were able to grow and root reasonably well but cereal production was unsuccessful. Severe compaction, poor structure and high bulk densities in the subsoil, as measured by special studies conducted in 1987 and 1988 in addition to soil density monitoring, are considered to be the main constraints to higher productivity of cereals.

4.3.5 Root Distribution

Cereal plots had plentiful to abundant roots in the topsoils, but only a few roots in the subsoil to about 40 cm depth from surface. Soil densities are excessive and likely prevent deeper rooting by grains.

Forage roots were abundant in the topsoils, and restricted but present through the subsoil, ending about 15 cm into spoil. Buried gypsum and ash layers seemed to increase the depth of plentiful roots in subsoils by about 10 cm. While crop yields responded to increasing buried ash thicknesses, this was not apparent in the rooting pattern.

4.3.6 Interaction

Forage yields on the control (Treatment 1) were very similar to those on Treatment 2 of the Subsoil Depth Experiment, in both cases subsoil thickness being 25 cm. The lack of differences in subsoil chemistry in response to subsurface ash amendments (Treatments 3, 4, 5) indicates that, to date, the ash has not been beneficial as a barrier to upward salt movement but it has contributed to higher forage yields. The latter is attributed to increased root zone volume and larger moisture storage. Note, however, that buried ash in the Torlea Experiment Treatment 7 was detrimental to yields. Consideration should be given to testing ash as a subsoil amendment, creating a loam rather than a clay loam subsoil, reducing density and increasing permeability in the process. Such a subsoil should be more readily leached, should have higher soil moisture availability, and should form a better rooting environment. The trafficability problems encountered when ash is used as a topsoil amendment should not be as serious.

4.4 SLOPE DRAINAGE EXPERIMENT

4.4.1 Crop Yields

Null Hypothesis:

1. Crop productivity is not a function of slope, position or aspect in the reclaimed landscape. If rejected, quantify the effect of slope, position and aspect.

The null hypothesis is rejected. Forage productivity increased downslope (13% difference between upper and lower position) but yields were not affected by slope angle or aspect. Nevertheless, all yields were generally poor, averaging 1780 kg/ha, in comparison to farmers regional yields of 3,225 kg/ha. Depth to spoil on the upper and middle slopes averages 65 cm and on lower slopes it is about 50 cm. Average yields were below those on all treatments of other BRSRP experiments except those on spoil alone in the Torlea Experiment. This may be attributed to comparatively fewer legumes surviving on the Slope Drainage Experiment. Note that the Slope Drainage Experiment was seeded one year earlier with similar seeding rates of alfalfa but the resultant swards differed.

4.4.2 Soil Salinity

Null Hypothesis:

1. Downslope salt transport is independent of slope and aspect. If rejected, quantify effect of slope and aspect.

This null hypothesis is rejected.

4.4.2.1 Position effects. Topsoils in lower positions were initially more saline than those of mid and upper positions. Over time all topsoils improved, that is, salinity declined, but those in lower positions improved more so that all were similar in 1986. This is attributed to greater leaching in lower positions resulting from runoff from upper slopes. Also it may be related to improved drainage of lower slopes brought about by ditching to drain ponding areas within the compound, adjacent to the plots.

Upper subsoils did not reveal any position effects. In lower subsoils, saturation percentage and SAR were greater in the lower positions that in others in 1984, but these differences disappeared by 1986. There were no position effects on spoils.

Since all positions were fairly dry and had deep water tables (> 185 cm), the slope positions as established in this experiment do not test classical groundwater recharge, lateral flow and discharge positions characteristic of hilly or knob and kettle terrain. Instead, this experiemnt is entirely within a recharge area. Caution is therefore advised in extrapolating results to larger areas.

4.4.2.2 Treatment effects. Major responses to slope angle and aspect occurred in the upper subsoil. Treatments 2 and 3 (10N and 5S, respectively) had higher EC, Na and SAR levels than the other treatments in 1985 and 1986. There is no apparent reason for this response other than the possible influence of compound runoff through the bases of these particular treatments. Examination of data reveals that lower and middle positions are most affected in these treatments although this was not statistically significant. Soil moisture data do not reflect either wetter or drier conditions in Treatments 2 or 3 than others.

4.4.2.3 Year effects. As in other experiments, there was leaching and improvement of topsoils in all treatments, and upper subsoils of Treatments 1 and 4 from 1982 to 1986. Upper subsoils of Treatments 2 and 3 degraded especially in the last two years. Lower subsoil had increasing EC over time and declining SAR, the latter in lower slopes only. Upper spoil had declining SAR but increasing EC and Na levels in 1986. These results indicate leaching of upper profiles and salt accumulation in the 50 to 100 cm interval.

4.4.3 Soil Moisture

As might be expected, soil moisture content in the upper 55 cm increased downslope, south aspects were drier than north aspects, and 10° slopes were drier than 5° slopes. Lower positions have shallower spoil than middle and upper positions and this was reflected in moisture readings. The spoils appear to be moist nearly throughout; however, moisture levels are well below saturation percentage. As in other experiments, the spoil moisture does not appear to be extractable by crops.

4.4.4 Bulk Density

Topsoil and spoil bulk densities are normal but subsoil densities are excessive, averaging 1.60 g/cm^3 in 1987. This probably inhibits forage productivity and would not be acceptable for cereal production. Differences among positions, aspects or slope angles are small and meaningless in practical terms.

4.4.5 Root Distribution

Forage roots were plentiful to a greater depth than in other experiments. This may be partly due to a dominance of grasses versus grass - legume mixtures in the other experiments. Nevertheless, roots generally did not penetrate more than about 15 cm into the spoil. Lower positions therefore had a slightly shallower root zone but yields were higher, attributable to increased soil moisture from runoff and lateral flow.

4.4.6 Interaction

Increasing yields in progressing from upper to lower slopes reflect the importance of moisture supply. Apparent inferior soil conditions in lower position soils, based on initial slightly more saline topsoils and subsoils that are some 15 cm shallower, produced greater yields. This is attributed to surface and possibly subsurface downslope water movement.

4.5 COMPARISON OF EXPERIMENTS

4.5.1 Crop Yields

Forage production on the reclaimed lands was successful and is recommended. Cereal yields were very low, attributed to severe subsoil compaction; therefore, cereal production is not recommended on the soils as reconstructed. A summary of yields of the recommended treatments, based on production within each experiment as well as the best available regional yield data are presented in Table 55.

In order to match farmer's yields in the region, 225 cm of subsoil replacement is needed according to the Subsoil Depth Experiment results.

The Torlea Experiment indicates that only 30 cm of B and C mix is required. These differences between the two exeriments are astounding, considering that the Subsoil Depth Experiment has subsoil materials of better chemical quality. Statistical analysis of yield data from the Bottom Ash and Slope Drainage experiments indicated yields to be well below farmer yields. The subsoils used in these experiments are the same as those in the Subsoil Depth Experiment. In order to raise yields, deeper subsoils are recommended. While buried ash placement, in the Bottom Ash Experiment, contributed to higher average yields, the increases were not statistically significant. In order to dispose of ash, it might be feasible to apply a thicker buried layer of ash and this may contribute to greater yields than observed. Note, however, that buried ash in the Torlea Experiment resulted in decreased yields.

In the author's judgement, yield comparisons alone are unsatisfactory for recommending the best soil treatments. The questionable target yields are a concern. However, the excessive subsoil densities and potential for salt accumulation within the subsoil below about 60 cm makes it necessary to recommend treatments based on soil characteristics. This issue is addressed in more detail later.

Table 55. Comparison of yields from recommended treatments based on productivity of each experiment and farm yields, 1983 to 1986.

	Subsoil Depth	Torlea Soil	Bottom Ash	Slope Drainage	ARA4A[a]
			Forage		
Recommended Treatment	b	3	1		
Subsoil Thickness cm	225	30 (B+C)	25	50	Natural Soil
Mean Yield kg/ha	3190	3510	2015	1780	3190
			Cereal		
Recommended Treatment	3		1		
Subsoil Thickness cm	65		25		Natural Soil
Mean Yield kg/ha	970		735		2060

[a] Agricultural Reporting Area No. 4A, 1983 to 1986 mean. (1972 to 1979 forage mean was 3140 kg/ha)

[b] Estimated yield based on linear relationship of subsoil depth versus yield.

4.5.2 Soil Salinity

In all experiments, topsoils in treatments with subsoils over spoils showed marked improvement in topsoil quality, mainly in the first couple of years. Upper subsoils initially degraded or remained unchanged and then improved the last couple of years. The above are the result of leaching of salts from the upper profile. Additions of surface ash or growth of forages versus cereals enhanced this process. Salt accumulation is evident in the lower profile and the depth is governed by the depth to spoil. In deep spoils, say greater than 135 cm, there are two salt accumulation zones: the first between 40 to 100 cm; and the second 15 cm above spoil to 20 cm or more below the spoil interface. The upper zone is where salts leached from the upper profile are evidently accumulating and, in the long term, are expected to match depths of salt concentration in natural soils. The lower zone apparently represents leaching of salts from the subsoil into spoil, likely by unsaturated flow along cracks, and possibly by upward movement of sodium salts by diffusion through the soil matrix. In treatments with shallower subsoil, say less than 100 cm to spoil, the two salt concentration zones overlap.

More time is needed to determine: whether leaching continues to remove the salts from the upper subsoil; how deep the salt-free zone will be; and, at what depth salt accumulation will stabilize. If the reclaimed soils develop as Solonetzic soils, then salinity levels should continue to decline to a depth of about 40 cm, but SAR levels will remain above 12. If the reclaimed soils develop as Chernozemic soils, then both EC and SAR values should decline for at least 60 cm. Salt accumulation zones should begin at about 40 cm and 60 cm, respectively. Salinity levels in these accumulation zones would likely exceed 10 mS/cm, making these zones unsuitable. It is evident, to date, that the spoil affects about 15 cm of subsoil above the interface, either by upward diffusion of sodium or by restricted leaching of salts from above. The depth to spoil should therefore be at least 55 cm or 75 cm, respectively, to permit formation of Solonetzic or Chernozemic soils similar to those in the area. Placement of 15 cm of topsoil over 60 cm of subsoil over spoil should permit reclaimed soils to develop to resemble better quality unmined soils in the area, in terms of soil chemical characteristics. However, soil physical characteristics of lands reclaimed using construction methods employed in this study are inferior to those of unmined lands and will reduce yields.

A major finding of this study with respect soil monitoring is the need to improve standarization of laboratory procedures, particularly saturation percentage. Results have clearly demonstrated that lab reported salt concentrations lead to different conclusions than adjusted values in some instances. In this project, the adjusted values generally indicate more favorable conditions; hence, if any erroneous conclusions have been reached they would be on the conservative side and should increase the safety margin.

4.5.3 Soil Moisture

Even though rainfall has been below long-term averages during the five-year period and crops have suffered from severe drought, there has been appreciable salt movement within the profiles. A study of the rainfall pattern and soil moisture regime suggests that major salt leaching occurs via unsaturated flow following storm events. Topsoils have clearly improved; upper subsoils, within many treatments, have improved; lower subsoils and spoils have generally deteriorated. Continued improvement in upper subsoils is expected and as salts are leached, they will likely accumulate lower in the profile either in subsoil, spoil or both.

Soil moisture levels at all depths were well below saturation throughout the monitoring period. This indicates absence of shallow water tables and eliminates capillary rise as a mechanism for upward salt movement within the setting of these experiments. Recommendations for soil reconstruction are therefore applicable to "recharge" areas within a hydrogeological regime.

Moisture supply within the root zone is a key factor in determining crop yields. Cereal roots could not penetrate the compact subsoil successfully; therefore, productivity was determined by topsoil moisture storage and frequency of rain. Drought periods or stresses caused by crop spraying combined with drought had a devastating impact on productivity.

Forage productivity was governed by moisture available in the subsoils. Deeper subsoils contributed to higher yields where subsoils were highly compacted as in the Subsoil Depth Experiment. On the other hand, in the Torlea Soil Experiment, chemically inferior and shallower subsoils produced much better. The main difference was a lack of compaction in the Torlea subsoils.

Therefore, it appears that soil handling procedures that minimize compaction are a good substitute for replacement of deeper materials. In fact, in order to attain sustainable yields comparable to farmer's yields and considering the expected depths to the salt accumulation zone, it will be necessary to handle subsoils in a manner that results in good moisture availability (i.e., provides good root penetration and optimum moisture storage capacity).

4.5.4 Soil Bulk Density

The monitoring of soil density clearly indicated that densities are excessive and well beyond limits that inhibit crop performance. Yield results show forage did not suffer as much as cereals. The apparent differences in densities between Torlea Soil plots and those of other experiments are attributed to construction procedures but exact details were never monitored.

Anomalous soil density fluctuations are difficult to explain. Regression analysis to calibrate both the moisture and density probes indicated r^2 values to be reasonable (e.g. moisture $r^2 = 0.79$, density $r^2 = 0.71$, in 1986). Moisture probe calibrations each year produced similar equations but density probe calibrations produced fairly different equations from year to year. It is not known whether the density probe was malfunctioning or whether it may be more sensitive to atmospheric soil moisture, or depth fluctuations. Results of density probe and gravimetric sampling in 1987 indicated probe readings to be unreliable in the topsoil and upper subsoils but they seemed to be satisfactory for lower layers. Nevertheless, gravimetric determinations of subsoil bulk densities in the Subsoil Depth and Bottom Ash experiments indicated excessively high densities in subsoils seven years after soil reconstruction.

4.5.5 Root Distribution

Rooting patterns were fairly similar throughout the Subsoil Depth, Bottom Ash, and Slope Drainage experiments. In forage plots, roots were "plentiful to abundant" in topsoils, "few" in subsoils to 40 to 60 cm, then "very few" to 120 to 140 cm, or 15 cm into spoil, whichever was shallower. In the Torlea Soil Experiments there were "plentiful" roots to about 35 cm where subsoils were deeper than 35 cm. Cereal roots were "plentiful" in topsoils, "few" in subsoils to 30 to 40 cm below ground surface, or "few" to a depth of 15 cm into spoil in shallower spoil treatments. Both crops clearly had difficulty rooting properly in the subsoil as indicated by exped, compressed or flattened roots and occurrence of root "mats" above the spoil interface in shallower subsoil treatments.

4.5.6 Soil Depth

To create reclaimed soils that are comparable in quality and productivity to unmined soils in the area, it is recommended that 15 cm of topsoil be placed over 60 cm of subsoil, over spoil. It is essential to replace the subsoil in a manner that optimizes soil moisture storage and availability.

If compacted, subsoils must be deeper (>225 cm) to obtain yields comparable to those obtained by farmers in the region. However, when a salt accumulation layer develops (beginning at 60 cm), yields are expected to decline considerably. At this time there is no assurance that natural amelioration of compaction will occur within at least 25 years.

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APPENDIX A

BATTLE RIVER SOIL RECONSTRUCTION PROJECT

SUMMARY OF 1987 AND 1988 RESULTS

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SUMMARY

The Battle River Soil Reconstruction Project (BRSRP) was established in 1979 to determine the most effective methods of reclaiming lands disturbed by surface mining of coal in the Battle River Coal Fields. This project is located about 20 km north of Halkirk on lands transferred from Manalta Coal Ltd. to the County of Paintearth. The Project is comprised of four experiments:

1. Subsoil Depth
2. Torlea Soil
3. Bottom Ash
4. Slope Drainage

The primary objectives of this research program are as follows:

1. To determine the required depth of suitable root zone material to be replaced over sodic mine spoil to ensure that mined land, particularly in the Battle River Coal Field, meets reclamation objectives. In this area, the reclamation objective is to return mined land to former levels of capability.
2. To develop methods of sustaining re-established productivity with emphasis on controlling salt movement from mine spoil into the reconstructed root zone.
3. To develop treatments which will minimize soil quantities needed to restore the original land productivity.

In 1986 the first five-year term of continuous intensive soil and crop monitoring was completed and five-year results are analyzed in the main report.

A new phase of the program was initiated in 1987, the main effort being to maintain the plots while substantially reducing monitoring activities. In 1987 and 1988, the crops on the four experiments were continued unchanged (that is, cereals on cereal plots of Subsoil Depth and Bottom Ash experiments, and forage on other plots). Crop yield, soil moisture and soil density monitoring were continued in 1987 while soil chemistry would be analyzed only periodically, every three to five years. In 1988 crop yields were monitored on the Subsoil Depth and Torlea experiments.

Important results of the 1987 and 1988 seasons are summarized as follows:

1. Forage yields were below the average recorded for the previous four years on each experiment. This is attributed to dry spring conditions and may also be due to aging forage stands. Generally, Torlea Soil plots yielded best, followed by Subsoil Depth, then Bottom Ash and Slope Drainage. Yields on Torlea plots with subsoil, and the deeper Subsoil Depth plots (165 cm and 335 cm subsoil) had forage yields matching or exceeding farmers' average yields, based on 1983 to 1988 means: all other plots yielded less. Results from 1987 and 1988 of particular interest to each experiment are:

   Subsoil Depth - Treatments 5 (165 cm subsoil) and 6 (335 cm subsoil) yielded better (about 130% and 150%, respectively) than the average of Treatments 1 (no subsoil), 3 (65 cm subsoil) and 4 (135 cm subsoil) which were all similar. Treatment 2 (25 cm subsoil) yielded lowest, about 65% of the average of Treatments 1, 3 and 4. These differences, however, are not statistically significant due to considerable variation among replicates. Nevertheless, it appears that the deep rooted forages could take advantage of extra soil moisture stored in deeper subsoils (165 cm plus).

   Torlea Soil - Results of 1987 and 1988 monitoring closely match the 1983 to 1986 yield pattern. Treatment 1 (spoil) was a failure. Treatment 2 (topsoil over spoil) produced lower yields but not significantly different from those of Treatments 3 to 7 with subsoil. The trend, not significant though, was for yields to increase with increasing subsoil thickness. Buried ash did not benefit yields and there was no apparent difference between B+C materials and C materials. In the long term, yields increased from control to gypsum to ash amendments although variations occurred from year to year.

Bottom Ash - In 1987 buried ash was detrimental to yields but over five years Treatment 5 (45 cm ash) yielded best. It seems that in normal years buried ash is advantageous in contributing to higher yields, but in dry years it is detrimental. In the long term, however, there were no statistical differences among treatments.

Slope Drainage - There were no significant differences in yields among treatments but the planned comparisons indicate a significant increase in yields downslope. This is attributable to increased moisture supply, and follows the pattern established from 1982 to 1986.

2. Cereal yields in 1987 were slightly higher on the Subsoil Depth plots than during the previous five years on all treatments, except for Treatment 1 (no subsoil) which yielded about the same. On the Bottom Ash plots 1987 yields were below the previous five year average. In 1988 all cereal plots failed and were not harvested. This may be attributed in part to spray damage as 1988 was a wetter year than 1987, and the crops were initially well established.

   The very poor cereal yields throughout the 1982 to 1988 period indicate that cereal production on these reclaimed lands has been unsuccessful, and well below farm averages.

3. Soil moisture levels in 1987 continued to be very low under forage stands and generally followed previous patterns, for example, no perched water tables, moist spoils but moisture not extractable by crops, and increased moisture in lower slope positions. Cereal plots had "available" moisture in the root zone but it appears that cereal roots were not able to penetrate the subsoil and extract this moisture.

4. Average soil bulk density levels in the Torlea Soil Experiment appear to be within normal limits for good agricultural soils, but they exceed these limits in all other experiments as shown below.

	Subsoil Depth[a]	Torlea Soil[b]	Bottom Ash[a]	Slope Drainage[b]
	Bulk Density g/cm^3			
Topsoil (0 to 15 cm)	1.34	1.13	1.32	1.34
Subsoil (15 to 30 cm)	1.80	1.09	1.76	1.58
Subsoil (30 to 45 cm)	1.77	1.28	1.75	1.80

---

[a] Measured gravimetrically

[b] Measured by probe (note that the probe readings overestimated topsoil density and underestimated upper subsoil density where comparisons of probe and gravimetric determinations were made)

5. Soil structure examinations in the Subsoil Depth and Bottom Ash experiments revealed that the reclaimed soils are characterized by topsoils which are similar to those of agricultural lands; however, subsoils are generally very dense and compact. They have weak subangular blocky to massive structure with few, fine planar voids and very few, fine tubular pores. There is little difference among treatments or crops, but forage roots penetrate the resistant subsoils whereas cereal roots do not.
6. Interactions of yields and soil properties are highlighted as follows:
   A. Moisture supply to crops was the key factor governing yields. Forages are able to root in the subsoils and extract moisture. Torlea soils yielded best apparently due to lower density and better resultant moisture supply. Subsoil Depth plots on deep subsoils were next best, due to increased rooting volume contributing extra moisture. Shallower subsoils in the Subsoil Depth Experiment and all treatments in the Bottom Ash and Slope Drainage experiments yielded less. It was expected that the lower positions of the Slope Drainage Experiment would have yielded higher than say the Bottom Ash and Treatments 2

to 4 of the Subsoil Depth plots. This lack of response may be explained by stand composition in that the Slope Drainage plots contained much less alfalfa than grass and therefore yielded less.

B. Cereal roots could not penetrate the dense poorly structured subsoils and were thus dependent on moisture reserves in topsoil and on frequent rainfall to replenish the supply of moisture. In dry years crops suffered extreme drought stress. In conclusion, the reclaimed soils in the plots are currently unsatisfactory for cereal growth.

C. Yield and soil moisture patterns established during 1982 to 1986 were more or less continued in 1987 and 1988. Consequently, findings of the last two years do not change conclusions reached in the five year report.

1. INTRODUCTION

The Battle River Soil Reconstruction Project, comprising four soil experiments, has been in operation since 1981 with standarized monitoring commencing in 1982.

A comprehensive monitoring of agronomic activities, soil moisture, density, salinity, crop yields and rainfall was conducted from 1982 to 1986.

In 1987 and again in 1988 monitoring was downscaled so as to maintain the plots at low cost but in suitable condition to obtain selected yield data and to allow future soil sampling and salinity analysis at periodic intervals.

This report summarizes agronomic and research activities carried out in the 1987 and 1988 monitoring of crops and soil physical properties on selected plots. Comparisons to earlier results are made as appropriate. Also plans for future monitoring are outlined.

2. ANNUAL FIELD PROGRAMS: ACTIVITIES AND METHODS

Agronomic activities conducted in 1987 and 1988 were similar in terms of cultivation, fertilization, weed control and harvest. The main differences were that in 1987 it was decided to underseed the "cereal" plots to forage, with a barley nurse crop, and in 1988 this decision was reversed and the "cereal" plots were again cultivated and seeded to wheat.

From 1982 to 1986 soil salinity, soil moisture and density were monitored. Soil salinity was not monitored in 1987 and moisture and density monitoring were discontinued in 1988. Concerns about soil physical conditions lead to an examination of soil structure, consistence, permeability and compaction in 1987 and 1988. These studies were done on selected plots on the Subsoil Depth and Bottom Ash experiments.

2.1 CEREAL PLOTS

2.1.1 Plot Preparation and Seeding

In both years cereal plots of Subsoil Depth and Bottom Ash experiments were prepared for seeding by cultivation and harrowing prior to fertilizing.

Fertilizer applications consisted of broadcasting and banding N, P, K at equivalent rates of 67-80-12 kg/ha and 47-61-12 kg/ha in 1987 and 1988, respectively. The plots were seeded to Harrington barley in 1987 and Neepawa wheat in 1988, each at rates of 50 kg/ha.

The 1987 underseeding of all cereal plots with crested wheatgrass at 4 kg/ha and Peace alfalfa at 8 kg/ha was successful in that good stands appeared to be established in spring 1988. A repeated attempt to establish this mixture in 1988 on the Bottom Ash Experiment was less successful in that only a poor crested wheatgrass stand developed. The 1988 summer drought probably killed the emerging alfalfa plants.

2.1.2 Weed Control

Each year "Target" was sprayed at recommended rates to control the major broadleaf weeds. The herbicide was applied with an ATV mounted sprayer. In 1987 heavy rains followed spraying, causing some renewed broadleaf weed germination and growth. The crop did not appear to suffer. However, in 1988 severe drought followed spraying causing very severe crop damage.

2.1.3 Cereal Harvest

The 1987 barley crop was harvested August 26 and 27, dry weights were determined and results were statistically analyzed. In 1988, the stress of drought combined with spraying caused a crop failure so no harvest was conducted.

2.2 FORAGE PLOTS

2.2.1 Crop Growth

The forage crops throughout the experiments generally remained in fair condition despite having suffered due to the dry conditions in the last few years, including 1987 and 1988.

Fertilizers were broadcast at equivalent rates of N,P,K of 44-56-12 kg/ha in 1987 and 47-61-12 kg/ha in 1988.

As of 1988, the Bottom Ash and Subsoil Depth experiments supported a mixture of alfalfa and brome, with alfalfa being slightly more prominent.

The Slope Drainage Experiment supported a mixture of alfalfa and grasses with brome and crested wheatgrass clearly dominating.

The forage plots of the Torlea Experiment were more variable likely due to several factors:

1. Treatment effect - The pure spoil plots are poorly established.
2. Subsidence - Plots 2.3.6C and 2.2.3B were periodically affected by water ponding since 1982.
3. Pocket gophers were again becoming a problem on some plots. These animals appear to have a preference for plots with a surface amendment of bottom ash. Their presence could affect yields. Alfalfa also appeared to do better on ash amended plots.

2.2.2 Forage Harvest

The forage harvests were completed on July 31, in 1987 and 1988. In 1987 yields on all experiments were measured, while in 1988 only the Subsoil Depth and Torlea Soil yields were measured. Entire plot fresh weights were recorded at the site. Replicate subsamples were taken to measure dry matter weights after oven-drying to a constant weight.

2.3 SOIL RESEARCH

2.3.1 Soil Moisture and Density

Neutron probe moisture readings were taken monthly, May to September, in 1987 but not in 1988. Likewise, a density probe was used to measure soil density in September, 1987. These same probes were used in previous years and are, respectively, a Campbell Scientific Hydroprobe Subsurface Moisture Gauge - Model Number 503 and Campbell Pacific Nuclear Corp. Density Probe Model 501.

2.3.2 Saturated Hydraulic Conductivity

Field saturated hydraulic conductivity was measured on one replicate of the Subsoil Depth Experiment in 1987, using a Guelph Permeameter.

2.3.3 Penetrometer Measurements

In 1987, soil strength measurements were taken with a recording cone penetrometer, on one replicate of the Subsoil Depth and Bottom Ash experiments.

In 1988, a centre cone penetrometer was used to measure the soil penetration resistance on each plot of the Subsoil Depth Experiment. Five replicate readings were taken at 5 cm intervals to a depth of 40 cm. These were averaged to produce one set of mean values for each plot. Where penetration resistance was so high the penetrometer overloaded, no reading was recorded.

2.3.4 Detailed Soil Descriptions

Soil physical properties of Subsoil Depth and Bottom Ash experiments were examined in detail on Replicate 2 in 1987 and all replicates in 1988. Soil pits to a depth of 50 cm were excavated on all plots and soil macrostructure was described in detail, considering horizon depth, texture, structure, consistence, planar and tubular voids, and rooting depth (after McKeague et al. 1986).

In addition, samples were taken in 1987 to determine field moisture content and soil bulk density at the sites described.

2.4 CLIMATIC DATA

The Alberta Research Council has an ongoing program to measure climatic parameters from a network of temporary stations in the region. One rainfall gauge is located in the compound and weekly precipitation data from it continued to be recorded during the 1987 and 1988 growing seasons. Results are presented in Table 1 and Figure 1.

Table 1. Rainfall at BRSRP compound, May to September.

MONTH	RAINFALL (mm) 1987	1988	MEAN 1983 to 1988
May	2	7	23
June	24	81	61
July	61	36	55
August	25	95	55
September	28	50	46
Total	140	269	240

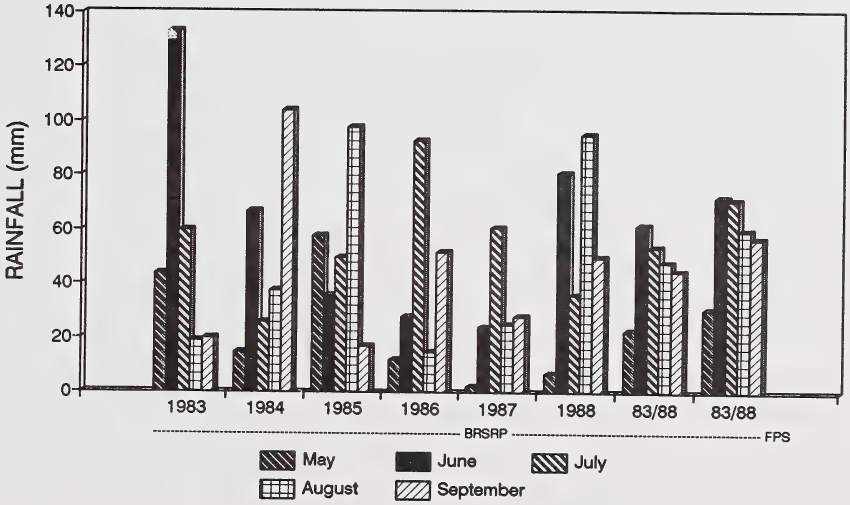


Figure 1. Rainfall at BRSRP compound and Forestburg Plant Site, 1983 to 1988.

3. STATISTICAL ANALYSES

The Annual Reports covering the 1987 and 1988 field seasons (Can-Ag Enterprises Ltd. 1988, 1989) and the Five-Year Report 1982 to 1986, outline the specific statistical procedures employed. In this report the statistically significant (at $p = 0.05$) findings are simply noted, where applicable. The 1987 and 1988 results were not combined with earlier results and analyzed as an entire data set; however, a subjective assessment indicates that statistical findings from 1983 to 1986 would likely remain similar if 1987 and 1988 results were added.

4. RESEARCH FINDINGS

4.1 SUBSOIL DEPTH EXPERIMENT

The objective of this experiment is to determine the optimum depth of replacement subsoil over sodic mine spoil required to sustain agricultural production. A 15 cm cover of topsoil (A horizon) overlays increasing thicknesses of subsoil which are as follows:

Treatment	Subsoil Thickness (cm)	
1	no subsoil	15 cm topsoil covers mine spoil or subsoil
2	25	
3	65	
4	135	
5	165	
6	335	

4.1.1 Crop Yields

Forage yields in 1987 and 1988 were generally poorer than earlier due to drought and there were no significant differences among treatments. Nevertheless, Treatments 5 and 6 with deeper subsoils (165 and 335 cm, respectively) outyielded all others and Treatment 2 (25 cm subsoil) was consistently poorest (Table 2).

Table 2. Forage yields, Subsoil Depth Experiment.

Treatment	Subsoil Thickness (cm)	1987	1988	Mean 1983 to 86	Mean 1983 to 88
		kg/ha			
1	none	1698a[a]	1769a	2167[b]	2022
2	25	1126a	835a	2077	1711
3	65	1633a	1306a	2387	2081
4	135	1414a	1306a	2703	2255
5	165	1871a	2120a	2804	2534
6	335	2164a	2474a	3305	2976
ARA4A[c]	unmined	2015	1345	3190	2690

[a] results followed by same letter indicate no statistical difference (within columns)

[b] planned comparisons (1983 to 1986 data) indicated linear increase in yield with increased subsoil thickness (this likely applies to 1983 to 1988)

[c] Agricultural Reporting Area 4A (Census Division statistics)

Greater variation among replicates is perhaps responsible for the lack of statistical differences. This is apparently due to the aging of the forage stands, to topographic differences and to severe drought. Small differences in plot micro-topography may contribute to differences in run-off and moisture storage which in turn affect yields more than subsoil depth.

Barley yields were higher in 1987 than over the last five years but were still below farmer's averages. Note that average barley yields are generally about 150 kg/ha more than average wheat yields (Table 3). Yields on Treatment 4 were significantly higher than in Treatment 1. Yields on all other treatments were intermediate but closer to those of Treatment 4 and no statistical differences occurred.

Therefore, on the basis of 1987 barley yields Treatment 4 (135 cm of subsoil) is superior.

Table 3. Cereal yields, Subsoil Depth Experiment.

Treatment	Subsoil Thickness (cm)	1987	1988	Mean 1982 to 86	Mean 1982 to 87
		kg/ha			
1	none	696a	--	785a	770
2	25	1314ab	--	928ab	992
3	65	1141ab	--	963b	993
4	135	1533b	--	973b	1066
5	165	1176ab	--	869ab	920
6	335	1101ab	--	844ab	887
ARA4A	unmined	1485	1720	2060	1965

Note: Barley was grown in 1987 and 1984, and wheat was grown in all other years on the plots. The ARA4A yields are for wheat.

In 1988, the wheat yields were not determined due to crop failure caused by drought and perhaps also by spray damage.

4.1.2 Soil Moisture

Measurements of soil moisture in 1987 indicated that on cereal plots, the frequency of monthly moisture contents greater than 5% above wilting point varied little between subsoil depth treatments as measured by moisture probe. Variations generally occurred within the upper 30 cm of soil on all treatments reflecting shallow rooting depth of cereal crops. Much of the moisture stored in the profile was not used by the crop despite the fact that it is within the easily available range (above wilting point plus 5%).

By contrast, on forage plots, depths to easily available moisture varied with the depth to spoil. Little easily available moisture was found in Treatments 1 to 5, in most months from about 30 cm depth to the depth of spoil. In Treatment 6 there was little moisture above 200 cm but moisture content increased to continuously moist (around field capacity) below 300 cm.

It thus appears that while observed rooting ends at about 150 cm, there may be some deeper taproots that extract moisture from deeper subsoil. Nevertheless, it is clear that forages can absorb moisture from considerable depths and thus the yield response to increasing subsoil thickness.

Differences in moisture availability between forage and cereal plots are clearly illustrated in Figure 2. For example, in Treatment 6 at the 15 to 30 cm depth, "cereal" soils were moist (easily available moisture) 80% of the time or four out of five months monitored; forages were moist only 20% of the time.

4.1.3 Soil Density

Gravimetric sampling of Replicate 2, Treatments 2 to 6, and density probe measurements of all plots in 1987 indicated the following soil densities:

Horizon	Depth (cm)	Mean Replicate 2 Gravimetric Bulk Density (g/cm^3)	Mean All Plots Probe Bulk Density (g/cm^3)
Ap	0 to 15	1.34	1.40
B1	15 to 30	1.80	1.62
B2	30 to 45	1.77	1.77

Densities in the B horizon are not different from each other but they are significantly higher than those of the A horizon.

These soil densities are very high and apparently were limiting to cereal root growth. Forage roots penetrate the subsoils in spite of these densities but it is not known whether yields are limited by density alone. Increased densities reduce the available moisture holding capacity of the soil and thereby indirectly limit yields.

The data indicate that, at depth, the probe and gravimetric measurements are comparable; however, topsoil and upper subsoil densities differ depending on method of measurement. Results may be affected by the access tube extension couplings (extra thickness of pipe) and surface disturbance. The latter would be due to loosening the soil to a depth of 30 to 40 cm to install the extensions, then tamping of the surface to ensure a good seal around the access tube.

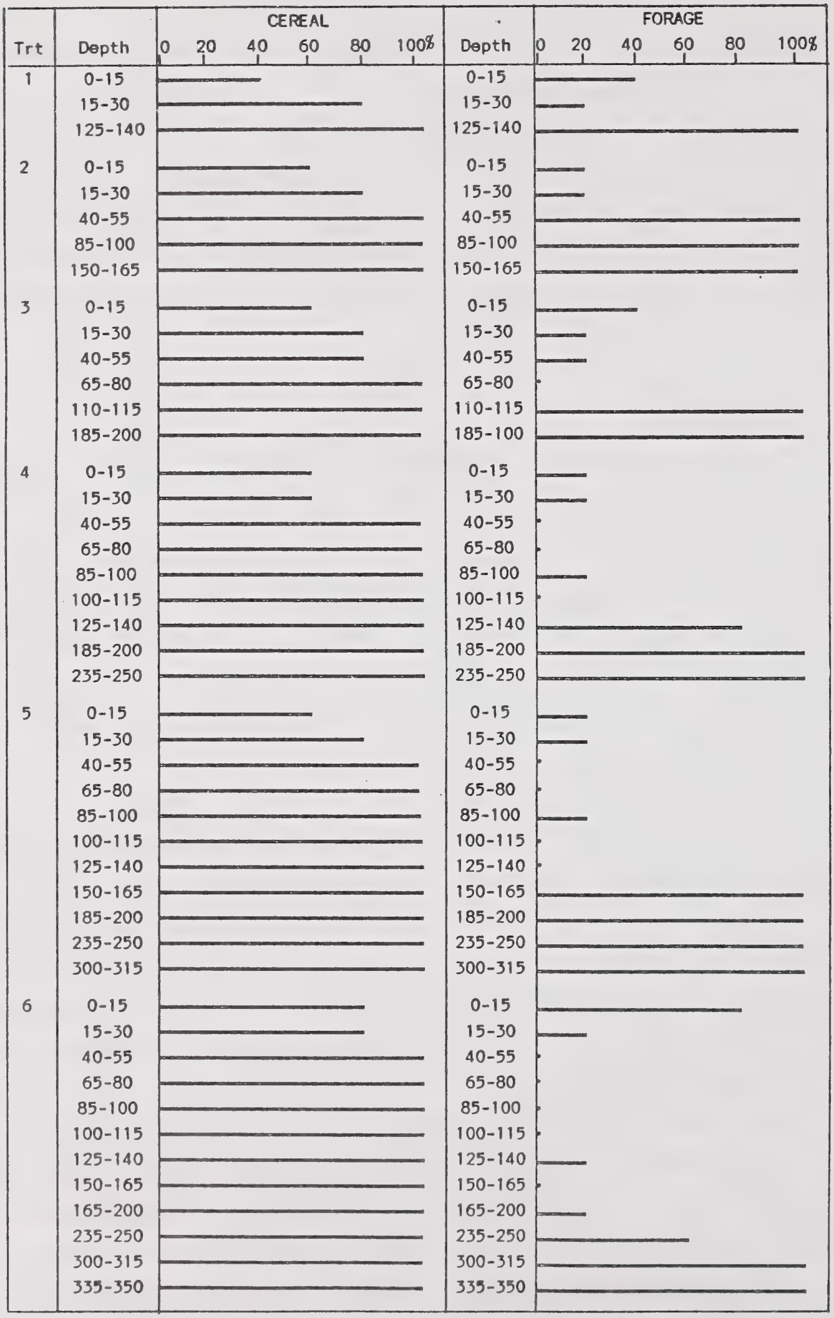


Figure 2. Percent frequency, months with moisture content easily available to plants, 1987, Subsoil Depth Experiment.

4.1.4 Soil Permeability

Field saturated hydraulic conductivity measurements were made in the upper subsoil using a Guelph Permeameter and it was found that:

1. permeabilities were very low (in terms of standard definitions),

   Cereal: 7.4×10^{-5} cm/sec.

   Forage: 1.6×10^{-4} cm/sec.

2. while there were apparent effects of crops (10 fold increase due to forage), the difference was not statistically significant.

Very low permeability is expected considering the high bulk densities and poor soil structure.

4.1.5 Penetrometer Resistance

In 1987, soils were generally dry at the time penetrometer readings were taken and results indicated very high resistance in topsoils. Cereal plots were slightly better due to their higher moisture content. Subsoils were generally too resistant to be penetrated.

Measurements taken in 1988 indicated similar results and conditions were again dry. Maximum penetration was 15 to 20 cm indicating that rooting is severely restricted, especially when dry. While measurements in unmined lands were not taken, it is estimated that under dry conditions the Bnt horizon of a Solonetz could not be penetrated.

4.1.6 Soil Structure

Soil descriptions made in 1987 and again in 1988 indicated the following main features:

Topsoil: (12 to 18 cm thick)
- predominantly weak fine granular; soft
- few to many, fine, random, discontinuous planar voids
- few to many, fine, random, discontinuous tubular voids

Subsoil 1: (7 to 15 cm thick)
- weak medium subangular blocky to massive; hard (50% of forage profiles, 75% of cereal profiles)
- weak medium platy; hard (50% of forage profiles, 25% of cereal profiles)
- common, fine, random, discontinuous planar voids

Subsoil 2: (10 to 20 cm thick)
- weak medium subangular blocky to massive, occasionally platy; hard and sometimes very hard
- common, fine, random, discontinuous planar voids
- few, fine, random, discontinuous tubular voids.

4.2 TORLEA SOIL EXPERIMENT

This experiment assesses methods of reclaiming lands mined from areas of Torlea Soils (Dark Brown Solodized Solonetz) which are only suitable for perennial forage crops. The objectives are to identify the preferred salvageable soil horizons or horizon blends within the Torlea soil profile for use in root zone reconstruction, and to assess various soil amendments as potential aids in crop production.

The treatments tested are:

Treatment	Observed Thicknesses
1	spoil
2	20 cm A/spoil
3	20 cm A/20 to 30 cm B+C/spoil
4	20 cm A/45 to 55 cm B+C/spoil
5	20 cm A/75 to 90 cm C/spoil
6	20 cm A/100 to 115 cm C/spoil
7	20 cm A/45 to 60 cm C/20 to 30 cm ash/spoil

Surface amendments of 15 cm bottom ash, 20 t/ha gypsum and a control were applied to each treatment.

4.2.1 Forage Yields

Forage yields in 1987 were about half of those in 1988 and in both years they were well below the average for the previous four years (Table 4). Treatment 1 is a failure and produced significantly less than others but there were no statistical differences between Treatments 2 to 7 in 1987 and 1988. Nevertheless, the superior treatments in all cases are subjectively considered to be Treatments 4, 5 and 6. There is a trend of increasing yields with increasing subsoil thickness. Buried ash is not apparently beneficial to yields when compared to treatments with a similar depth of subsoil alone. Also, there appears to be no difference between B and C horizon material versus C horizon in terms of yields.

Amendments were effective in that ash out-performed gypsum and control over six years although variations occur in individual years. The differences among amendments were not significant in 1987 and 1988.

4.2.2 Soil Moisture

Soil moisture monitoring in 1987 indicated that topsoils and subsoil in all plots were dry most of the time. Spoil layers were moist but as roots do not generally penetrate the spoil this moisture was probably not available to the plants. There was no evidence of a perched water table above the spoil.

4.2.3 Soil Density

Measurements of soil bulk density with the density probe in September of 1987 indicated average densities as follows:

Layer	Treatments	Density (g/cm^3)	Range (g/cm^3)
Topsoil	2 to 7	1.13	0.87 to 1.41
Upper Subsoil	4 to 7	1.09	0.95 to 1.30
Lower Subsoil	4 to 7	1.28	0.83 to 1.54
Spoil	1 to 7	1.31	0.87 to 1.52

Table 4. Forage yields (kg/ha), Torlea Soil Experiment.

Treatment	1987	1988	1983 to 86	1983 to 88
	kg/ha			
1	failure	failure	failure	failure
2	777	1752	1872	1670
3	812	1803	3514	2778
4	1026	2159	3700	2998
5	1280	2364	3761	3115
6	1175	2469	3813	3149
7	843	3032	3168	2758
n = 3 reps. x 3 amendments x no. of years				
Treatments 2 to 7				
Ash	1065	2112	3624	2945
Gypsum	912	2395	3292	2746
Control	979	2355	2986	2546
n = 3 reps. x 6 treatments x no. of years				

It is noteworthy that all topsoil and subsoil densities in the Torlea Soil plots are lower than in those of other experiments. The reason for this difference has not been explained to date but it is the author's view that this is due to construction technique. The Torlea Plots are narrow (4 m) so during construction much of the wheel traffic would have been confined to the plot edges, resulting in less packing of plot centers. Bulk densities and yields are measured in the central strips where soil conditions are most favourable. Over time, it is evident that several plots have subsided in the middle, further supporting this concept. All the other experimental plots are wider (6 m, 8 m and more) so that during construction there would have been more likelihood of traffic across the entire plot causing more packing throughout. There is also a possibility that moisture conditions or freezing affected densities too, as some Torlea plots were constructed in winter following delays caused by excessive wetness in summer.

4.3 BOTTOM ASH EXPERIMENT

The objective of this experiment is to assess the potential of bottom ash to act as a capillary barrier to upward movement of sodium salts from mine spoil into replaced subsoil. Forage and cereal yields, moisture levels in 1987, and soil physical properties were assessed in 1987 and 1988 with regard to the following treatments:

Treatment	Soil Composition
1	15 cm topsoil/25 cm subsoil/spoil
2	15 cm topsoil/25 cm subsoil/gypsum/spoil
3	15 cm topsoil/25 cm subsoil/5 cm ash/spoil
4	15 cm topsoil/25 cm subsoil/15 cm ash/spoil
5	15 cm topsoil/25 cm subsoil/45 cm ash/spoil

Cereal yields on the Subsoil Depth and Bottom Ash plots continued to be very poor, averaging from 30 to 55% of farmers' average yields during this period.

From a yield perspective, cereal production on these reclaimed lands is not recommended. Forage production is recommended and can match farmer's yields on deep (>225 cm) compacted subsoil, or on much shallower (>25 cm) non-compacted subsoil. A minimum depth of 60 cm of non-compacted subsoil was recommended after five years based on soil interpretations. This depth of 60 cm is again recommended as a minimum, pending further soil studies, but subsoil physical characteristics must be improved to obtain acceptable yields.

4.3.1 Crop Yields

Forage yields recorded in 1987, the previous four years, and the overall average are given in Table 5. In 1987, treatments with little (5 cm) or no buried ash out-performed Treatments 4 and 5 with increasing thickness of ash. In earlier years Treatment 5 yielded best although treatment differences were not significant. It therefore seems that buried ash is especially detrimental during very dry years, but advantageous over the five years.

Table 5. Crop yields (kg/ha), Bottom Ash Experiment.

	Forage			Cereal		
Treatment	1987	1983 to 86	1983 to 87	1987	1982 to 86	1982 to 87
	kg/ha					
1	1393bc	2015a	1891	809a	735a	747
2	1228abc	1974a	1825	523a	604a	591
3	1550c	2416a	2243	611a	732a	712
4	983ab	2204a	1960	390a	580a	548
5	814a	2892a	2476	592a	748a	722

Barley yields were also very poor in 1987 averaging 585 kg/ha. While there were no significant differences among treatments the highest yield was on Treatment 1, the lowest was on Treatment 4 and remaining treatments were intermediate and similar.

4.3.2 Soil Moisture

Percentage frequency of months with readily available moisture was reported for the 1987 growing season (Can-Ag Enterprises Ltd. 1988). Results indicated generally dry conditions; that cereal plots were more moist than forage plots in the topsoil and upper subsoil; that treatments with increasing thicknesses of buried ash were progressively drier in the lower subsoil (note that interpretation is complicated by the lower moisture retention of ash); that forages were able to extract moisture to a greater depth than cereals; and, that there was no evidence of a perched water table above the spoil.

4.3.3 Soil Density

In 1987 both density probe and gravimetric measurements of soil bulk density were made and results are similar to those reported for the Subsoil Depth Experiment. Specifically:

Horizon	Depth (cm)	Replicate 2 Gravimetric Bulk Density (g/cm^3)	Trts 1 to 3 Probe* Bulk Density (g/cm^3)
Ap	0 to 15	1.32	1.44
B1	15 to 30	1.76	1.67
B2	30 to 45	1.75	

* Treatment 4 and 5 excluded due to influence of ash.

It is evident that the topsoil density is too high and subsoil density is too low as measured by density probe, likely attributable to the disturbance caused by installing access tube extensions.

The high soil densities in the B layer are certainly restrictive to cereal growth and perhaps to a lesser degree to forage growth.

4.3.4 Penetrometer Resistance

Soils were dry when penetrometer readings were made and results indicated that the penetrometer resistance was within acceptable limits for rooting to a depth of 3.5 cm on forage plots and a maximum of 10 cm on cereal plots. Measurements must be taken during wetter conditions to obtain meaningful results; nevertheless, the penetrometer measurements are in line with the high densities, low moisture, and poor soil structure.

4.3.5 Soil Structure

Examination of soil structure revealed conditions which are similar to those on the Subsoil Depth Experiment, specifically:

Topsoil:	-	predominantly weak fine granular; soft
(10 to 20 cm	-	few, fine, random, discontinuous planar voids
thick)	-	very few, fine, random, discontinuous tubular voids

Subsoil 1: (10 to 20 cm thick)
- weak subangular blocky to massive, occasionally platy; hard to very hard
- few, fine, random, discontinuous planar voids
- very few, fine, random, discontinuous tubular voids

Subsoil 2: (10 to 20 cm thick)
- weak subangular blocky to massive; hard to very hard
- few, fine, random, discontinuous planar voids
- very few, fine, random, discontinuous tubular voids.

4.4 SLOPE DRAINAGE EXPERIMENT - RESULTS

This experiment is designed to determine the effect of degree of spoil levelling (slope) and aspect on the productivity of forage crops. Reconstruction profiles consist of 15 cm topsoil (A horizon) over 50 cm subsoil over spoil. Treatments consist of a combination of 5 degree and 10 degree slopes with northern and southern aspects and are as follows:

Treatment	Description
1	5 degree slope to north aspect
2	10 degree slope to north aspect
3	5 degree slope to south aspect
4	10 degree slope to south aspect

Crop productivity, moisture and bulk density were compared at upper, mid and lower slope positions in 1987, but in 1988 the plots were only maintained.

4.4.1 Crop Yields

In 1987 there were no statistically significant yield differences between treatments or slope positions, likely due to overall poor yields caused by drought. However, yields increased from upper to lower slopes as in previous years (Table 6). Increasing yields downslope are attributed to increasing moisture supply.

Table 6. Forage yields, Slope Drainage Experiment.

Position	1987	1982 to 86	1982 to 87
	kg/ha		
Upper	625a	1650a[2]	1479
Middle	668a	1823a	1630
Lower	943a	1859a	1706
n	8	40	48

[2] planned comparison indicates significant linear relationship

4.4.2 Soil Moisture

Neutron probe moisture measurements taken monthly during the 1987 growing season indicated a continuation of previous trends: moisture availability increased downslope.

4.4.3 Soil Density

Soil bulk densities as measured by density probe indicated no significant differences among treatments or positions. Apparent densities in 1987 were:

Topsoil	0 to 15 cm	1.34 g/cm^3
Subsoil	15 to 30 cm	1.58 g/cm^3
Subsoil	40 to 55 cm	1.80 g/cm^3

If comparisons of Subsoil Depth and Bottom Ash gravimetric versus probe readings are considered, one would estimate that topsoil density is actually lower and upper subsoil density is higher than shown here. Subsoil densities are excessive for good cereal crop root growth and possibly limiting to forage root growth.

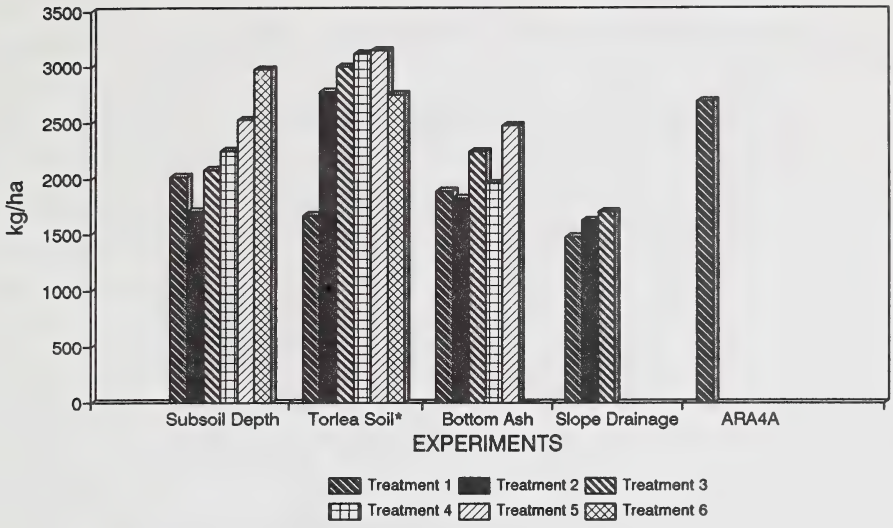
5. CONCLUSIONS

The forage and cereal mean yields during the 1982 to 1988 monitoring period are shown in Figures 3 and 4. Regional yields based on Agricultural Reporting Area 4A (Census Division 7) are provided for comparison. Note that on the cereal plots, barley was grown in 1984 and 1987, and wheat was grown in all other years. No adjustments to reported cereal yields were made to account for crop differences but farmers' average yields for barley are about 150 kg/ha higher than those for wheat.

It is evident that Subsoil Depth Treatments 5 and 6 (165 and 335 cm subsoil), Torlea treatments with subsoil (25 to 110 cm), and Bottom Ash Treatment 5 (25 cm subsoil, 45 cm bottom ash) all produced forage yields exceeding or within 10% below farmers' averages. Yields on all other plots were more than 10% below farm averages.

Cereal yields on the Subsoil Depth and Bottom Ash plots continued to be very poor, averaging from 30% to 55% of farmers' average yields during this period.

From a yield perspective, cereal production on lands reclaimed as these plots were is not recommended. Forage production is recommended and can match farmers' yields on deep (more than 225 cm) compacted subsoil, or on much shallower (25 cm or more) non-compacted subsoil. A minimum depth of 60 cm of non-compacted subsoil was recommended after five years based on soil interpretations. This depth of 60 cm is again recommended as a minimum, pending further soil studies, but subsoil physical characteristics must be improved to obtain acceptable yields.



* Note: For Torlea Soil, bars represent Treatments 2 to 7, not 1 to 6.

Figure 3. Mean forage yields for all experiments and regional farmers, 1982 to 1988.

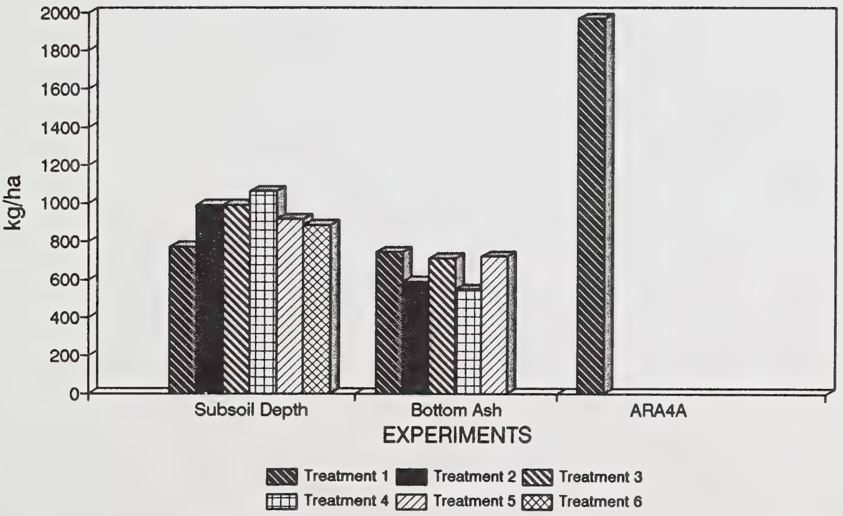


Figure 4. Mean cereal yields for Subsoil Depth and Bottom Ash experiments and regional farmers, 1982 to 1987.

6. RECOMMENDATIONS

Recommendations arising from the 1987 and 1988 programs are summarized below:

1. Target yields on reclaimed lands should be established in a scientific manner, for example, by monitoring a cross-section of farmer's fields in the area. Soil types, capability, management practices, rainfall, and yields for different crops should be known in order to be able to make sound comparisons. This is especially critical for forage crops.
   Current average farmer yields are based on Census Division data. There are no yield breakdowns by soil type, stand composition, fertilizer applications, number of cuts, etc.
2. Alternative methods of reclaiming subsoils should be studied: the main objective being to produce a more favorable rooting zone in terms of physical characteristics (density, structure, water retention, permeability, etc.).
   Some practices to be considered include: different methods of subsoil replacement, biological amelioration (vegetation, rotations, earthworms), mechanical amelioration (shallow or deep subsoiling with different types of subsoilers), and mixing of bottom ash with subsoil. Trade-offs between material supply, handling costs, time and final soil quality must be examined to develop optimum procedures.
3. Characterization of soil physical properties in relation to root zone quality, moisture supply, and salinity management deserves more attention. Research on this subject is needed for unmined agricultural lands as well as for reclaimed soils.

7. REFERENCES

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APPENDIX B

LIST OF REPORTS PUBLISHED BY THE RECLAMATION RESEARCH TECHNICAL ADVISORY COMMITTEE

Reclamation Research Reports

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. $10.00**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. $10.00**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. $10.00**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their uninoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition.**
Hardy BBT Limited. 436 pp. $10.00

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that preceeds each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

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